GENETICS OF HEALTH AND LAMENESS IN DAIRY CATTLE

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DECLARATION

I declare that this thesis is the result of my own work and constitute the results of my research.

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DEDICATION

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ABSTRACT

For the modern dairy cow, advances in genetics and breeding for productivity has resulted in an increasing incidence of health disorders and reduced longevity. One of the most important health problems is lameness, which has led to significant economic, production and welfare consequences. A reduction in lameness will improve the economic future of the dairy industry through increased profitability and decreased welfare-related problems. Although positive attempts have been made by researchers and the industry towards improving lameness, it has remained a persistent ailment for dairy farmers. Further analysis of the genetic and environmental factors influencing lameness is warranted so that selection indices and management practices can be modified leading to improved health and welfare of the dairy cow.

Several factors that cause dairy cow lameness have been implicated. I reviewed previous studies on these causative factors as well as the association between lameness, longevity and fertility. It has also been suggested that lameness affects milk production of dairy cows, but reports on the association between lameness and daily milk yield of cows have varied among researchers. Using locomotion score data on 248 cows from the Langhill herd, I investigated the relationship between locomotion score which has a high genetic correlation with lameness and various explanatory variables and also the association between daily milk yield and lameness. The study revealed that the most significant factors affecting locomotion are management regime (high concentrate feed and all year indoor housing; low concentrate feed and outdoors in summer) and time of year when cows are locomotion scored. It also showed that lameness adversely affects the milk yield of later lactation cows, and that high yielding cows are more susceptible to lameness.

Housing environment plays a significant role in the health and welfare of dairy cows. With national type evaluation records, I estimated the association between housing systems and lameness-related type traits as well as genetic parameters for the locomotion traits. The analysis indicated that cows kept at pasture had favourable linear and composite type trait scores compared with cows in cubicles, straw yards and slatted floors or loafing yards. Locomotion score had strong genetic and phenotypic correlations with

the leg and feet composite. Bone quality, which is a new trait in the UK type classification scheme, was moderately heritable (0.23) and had a moderate and positive genetic association with locomotion and leg and feet composite. This suggests that breeding for flatter, more refined bones could reduce locomotion disorders and help improve the longevity of the dairy cow. Analysis of national data again showed reduced incidence of digital dermatitis (DD) for cows at pasture and those with flatter, more refined bones, higher locomotion score and better leg and feet composite. Estimates of genetic parameters indicated heritable variation of DD among cows and moderate genetic associations between DD and production traits and longevity. Incorporating DD in future selection indices will be useful for increased productive life.

Using random regression, I analysed changes in type traits associated with lameness (locomotion, rear legs, side view, foot angle and leg and feet composite) in relation to time (months) that cows had spent in cubicles before being classified. The general trend supported the fact that cubicle housing is unfavourable to these traits. There was significant evidence of a genotype x environment interaction, suggesting variation between bulls in the sensitivity of their daughters to cubicle housing with time.

CHAPTER 1

GENERAL INTRODUCTION

1.1 Lameness as a Health Problem

As a result of the negative genetic association between production and fitness, the United Kingdom's Farm Animal Welfare Council (1997) recommended in its dairy cow welfare report that "breeding companies should concentrate their effort primarily to selection for health traits so as to reduce current levels of lameness, mastitis and infertility". Whay et al. (2003) reported that lameness, limb lesions, mortality records, treatment records, lung pathology, feeding behaviour, and body condition were the most important animal-based measures of dairy cow welfare. Broom (2002) also pointed out the major welfare problems in dairy cows as lameness, mastitis, impaired reproduction and inability to show normal behaviour.

It is clear that lameness is a leading health problem in dairy cow production. Lameness compromises dairy cow welfare through pain and discomfort (Garbarino *et al.*, 2004), increased treatment costs (Kossaibati and Esslemont, 1997), impaired reproductive performance (Hernandez *et al.*, 2001; Melendez *et al.*, 2003), decreased milk yield (Warnick *et al.*, 2001; Green *et al.*, 2002) as well as increased involuntary culling (Sprecher *et al.*, 1997; Booth *et al.*, 2004) thereby reducing dairy cow longevity. The incidence of lameness has increased tremendously over the last decades. In the UK, its incidence has increased in dairy herds from <10% prior to 1980 (Russel *et al.*, 1982) to >20% after 1990 (Clarkson *et al.*, 1996). A report from Green *et al.* (2002) indicated that over 70% of the cows became lame at least once during their 7 month study. Bell (2004) reported that 85.7% of 624 dairy cows studied had at least one hoof lesion. Lameness has, therefore, remained a persistent and a growing health disorder in many dairy farms with significant economic, production and welfare consequences despite concerted effort being made by farmers to reduce it to an acceptable level.

1.2 Risk Factors for Lameness

Reducing lameness in herds is beneficial to the dairy industry through increased economic returns. As a result, lameness has attracted much attention over the last two to three decades (Boelling, 1999) and researchers have continued to describe the risk factors associated with lameness (Enevoldsen *et al.*, 1991a,b; Bergsten, 1994; Cook *et al.*, 2004) in order to profer strategies that would minimize the disorder in dairy herds. Many risk factors have been found to predispose cows to lameness. Most lameness causes have been associated with lesions of the claw horn as well as many other different factors - housing, flooring, hoof trimming, nutrition, calving, parity, stage of lactation, body weight, and genotype. Lameness is a recurrent problem and the degree and severity varies between farms. It is, therefore, still worthwhile to continue to investigate its predisposing factors with regard to current management systems relevant to different farms. This research should result in better management decisions and a reduced incidence of lameness on farms.

Hoof disorders are a serious problem in modern dairy cattle housing systems. In the UK, hoof lesions cause over 90% of lameness in dairy cattle (Logue *et al*., 1993; Murray *et al*., 1996). Reports from The Netherlands showed that over 70% of cows have at least one claw disorder (Somers *et al*., 2003; van der Waaij *et al*., 2005). Other reports indicated that, across countries, 25 to 30% of cows are treated per year for hoof disorders (Smith *et al*., 1986; Boettcher *et al*., 1998). Studies have shown that the occurrence of hoof lesions is influenced by the behaviour and social interaction of the animals (Leonard *et al*., 1995; Chaplin *et al*., 1999). An increase in the probability of clinical lameness with age has also been noted (Eddy and Scott, 1980; Baggott and Russell, 1981) and this has been attributed to a progressive decline in the quality of cow's hooves due to deterioration in shape and/or softening of the horn and internal structures (Rowlands *et al*., 1985) which occurs with increasing age. Different disease conditions including digital dermatitis (DD) result in hoof disorders. DD, an inflammation of the skin between the bulbs of the heel, is an infectious cause of lameness. DD accounts for up to 25% of all lameness cases in UK dairy cattle (ADAS, 2001) making it an issue of concern in dairy health improvement.

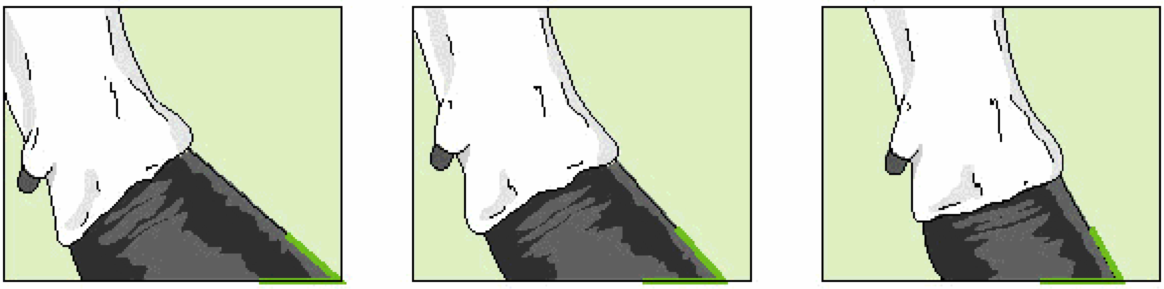
Reports have also indicated that high producing dairy cows tend to be at high risk of lameness due to the metabolic stress of high milk yield (Barkema *et al*., 1994; Warnick *et al*., 2001). Similarly, a review of 14 genetic studies (Ingvartsen *et al*., 2003) on the relationship between milk yield and health in dairy cattle revealved an unfavourable genetic association between milk yield and incidence of ketosis (0.26-0.65), mastitis (0.15-0.68), ovarian cyst (0.23-0.42) and lameness (0.24-0.48). Although increased production is considered to increase the level of lameness, yet significant improvement to ameliorate this problem has not been made (Defra, 2007). However studies have included locomotion as a predictor of lameness and, based on genetic correlations, have reported different associations between lameness and milk yield (a decrease, an increase and no change). However, based on my findings (chapter 3) high milk production is associated with high locomotion problems with resultant decrease in milk production.

1.3 Recording of Lameness in the UK

Since 1983, Holstein UK (HUK) (the breed society in the UK for Holstein-Friesians) has been type classifying heifers as part of a linear assessment scheme (Stott *et al.*, 2005). Analysis of these traits provides genetic information for selecting service bulls that transmit improved conformation to their offspring.

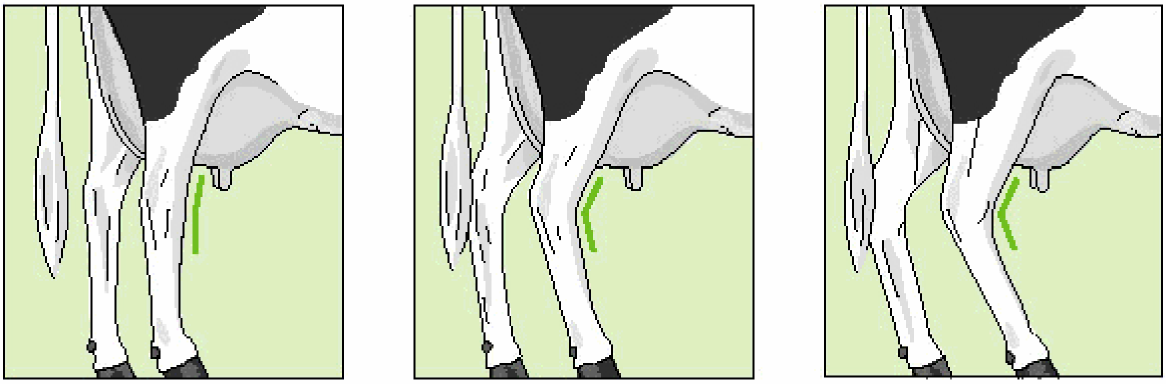
With this scheme various conformation traits which are related to legs and feet including the angle of the foot (FA) and the set of the rear legs (RLS) are recorded. All linear traits are scored on a standard scale of 1 to 9 which represents biological extremes. For FA and RLS, 1 denotes very low angle and straight hock and 9 indicates very steep angle and sickled hock, respectively. Figure 1.1 and 1.2 shows the diagrammatical descriptions of foot angle and rear legs set. In 1993, HUK included the scoring of a leg and feet composite which subjectively describes attributes of the legs and feet including locomotion.

Figure 1.1 Linear assessement of foot angle (i.e. angle at the front of the rear hoof measured from the floor to the hair line).



1-3 (Very low) 4-5 (Intermediate) 7-9 (Very steep)

Figure 1.2 Linear assessment of rear legs, side view (angle measured at the front of the hock)



1-3 (Straight) 4-6 (Intermediate) 7-9 (Sickled)

Source (A useful guide to Linear Assessment, Holstein UK)

Lameness and locomotion have been reported to be highly genetically correlated (Boelling and Pollot, 1998; Stott *et al.*, 2005). As a result, locomotion scoring, a technique which allows the subjective assessment of stride length and tracking as a cow walks on a level non-slippery surface, is used as a tool for detection and monitoring of herd lameness. In 1998, a 9-point locomotion scoring system (see chapter 4) was adopted for scoring UK national herds i.e. herds participating in Holstein UK's type classification scheme (Stott *et al.*, 2005). According to Whay (2002), the most appropriate scoring method is one that is easy to use and which also provides sufficient lameness data. This is of great importance particularly at the farm level to measure the number of lame cows at any one time. Thus, in addition to the national locomotion scoring system, a simple 5-point scoring system (chapter 3) was developed at a UK research farm for ease of adoption by many farmers. In 1999, HUK started the classification of bone quality, a trait which describes the fineness and flatness of bone (Brotherstone, unpublished). It is scored on a scale of 1 to 9 which represents thick and coarse and flat and fine bones, respectively.

Several lesions or diseases of the hoof have been reported as major odds of a cow becoming lame. Although DD can be treated with footbath solutions, treating a case of DD is expensive (ADAS, 2001). In 2002, Holstein UK included the recording of DD in its type classification scheme. Here, field officers record whether or not cows show evidence of DD. DD is scored on the presence or absence of lesions on the interdigital spaces of the cow's feet. With this information, genetic evaluation of DD and its association with other traits linked to lameness may be possible.

1.4 Genetic Relationships between Lameness, Type Traits and Disease

Locomotion traits are heritable and are used as indicator traits for lameness (Buitenhuis *et al.*, 2007). Estimating genetic parameters for locomotion and other type traits related to legs and feet is necessary in order to breed for reduced leg problems and consequently increased dairy cow longevity in herds. However, until this thesis such a study to investigate the genetic association between locomotion and other type traits has not been reported for the UK Holstein-Friesian dairy cows. Studies have indicated that leg conformation traits are genetically correlated with claw disorders (Reurink and van Arendonk, 1987; Boelling *et al.*, 2001; van der Waaij *et al.*, 2005). van der Waaij *et al.* (2005) analysed 8 claw disorders including DD and leg conformation traits. Results from the study showed that most of the claw disorders were heritable and that DD had a significant genetic and phenotypic correlation with locomotion and leg and feet composite. This suggests that resistance of cows to DD and subsequently lameness could be improved by selecting either for DD or these correlated traits. This could be a useful addition to future selection indices incorporating health and fertility traits. If DD is to be included in a selection index to reduce lameness and maximize profit then estimates of genetic parameters for DD and its genetic association with locomotion traits, longevity, fertility and production are required. Investigations of the relationships between DD and health traits are rare.

1.5 Genotype x Environment Interaction

If management conditions are unfavourable, then cows with good locomotion traits may not reach their productive potential and/or lifetime. Therefore, an aim of the breeder is to breed cows with good legs and feet. However, the question is what environment is the most favourable for reducing lameness? Perhaps a good approach is to determine the relationship between various housing systems, type traits and disease scores. Housing and flooring types play significant roles in the health of hooves. There is very little research information to indicate the association between different housing systems, flooring quality and locomotion traits. Also research dealing with the relationship between housing, flooring and disease (e.g digital dermatitis) and locomotion traits is scant in literature. This information is necessary in order to improve lameness in dairy herds. Most studies have dealt mainly with the incidence and prevalence of lameness or hoof lesions. Holstein UK record information on housing, flooring and digital dermatitis during type classification, and this will enable associations between type, DD, housing and flooring to be estimated.

Haskell *et al*. (2007) noted the importance of investigating the effect of farm environment on the health of dairy cattle as it may indicate that some farm environments are unsuitable for particular genotypes. Several studies have investigated the existence of genotype x environment interaction for production and fertility traits by random regression models (Calus and Veerkamp, 2003; Hayes *et al*., 2003; Bryant *et al*., 2006), but similar studies are scant for health traits in particular locomotion traits. The expression of genes in different housing environments through the performance of sires' daughters could be useful in evaluating sires for breeding cows with better leg and feet traits either for specific or a more general environment. This will in turn reduce lameness, increase longevity of cows and also increase producer profit in the long term. This is because profit for different producers may come from very different production environments and hence may require genotypes specific to their circumstances (Coffey, 2003).

1.6 Justification for Study

Reducing lameness is beneficial for the farmer through an increase in the lifetime production of the cow at minimal cost (Buitenhuis *et al*., 2007). As the emphasis on health and welfare increases, understanding the effect of genetic, environmental and disease factors influencing lameness becomes increasingly important. Most countries now include traits associated with legs and feet in their national selection index (Miglior *et al*., 2005). With the current interest in genetic improvement of health traits, additional

information is needed to help facilitate genetic evaluations for fitness as well as production and consequently enhance the overall breeding goal for dairy cows i.e. profit.
It is against this background that this thesis is undertaken and the studies explored evaluate the relationship between lameness, production and fitness-related traits as well as housing conditions.

1.7 Objectives

The overall objectives of this study were to estimate genetic parameters for lameness (locomotion) and asssociations with other health-related traits and with the housing environment.

1.7.1 Chapter Objectives

In chapter 2, I review previous studies on lameness in relation to the etiology (as relevant to this thesis), diagnosis and associations with other traits such as longevity, fertility and production.
In chapter 3, I explore the risk factors associated with lameness and the effect of lameness on milk yield in both 1st and later lactation cows. The analysis was based on data collected from Langhill herd at Crichton Royal Farm in Dumfriesshire, Scotland between 2003 and 2005.
In chapter 4, I estimate genetic parameters for locomotion and legs and feet traits and correlations between locomotion and these traits. I also evaluate the association between locomotion, type traits and different housing systems and flooring quality. Data used in the analysis comprised of 156,770 national type evaluation records of pedigreed first-lactation Holstein-Friesian cows calving from 2000 through 2006. Recording of housing information started in year 2000.
In chapter 5, I estimate genetic parameters for digital dermatitis and its association with locomotion traits. I also estimate approximate genetic correlations between digital dermatitis and lifespan (LS), fertility (calving interval (CI) and non-return at 56 days(NR56)) and production (milk and fat) from sire EBV. Similar relationships between locomotion traits and lifespan, fertility and production are also evaluated. Data comprised 93,391 national type evaluation records of pedigreed first-lactation Holstein-Friesian

cows that calved between 2002 and 2006. The recording of digital dermatitis commenced in 2002. Sire EBV and reliabilities for LS, CI, NR56, milk, fat and longevity were taken from the UK national evaluation records of May 2007.

In chapter 6, I investigated the genetic association between time spent in cubicles and locomotion type traits. Data comprised 96,938 national type evaluation records of first-lactation Holstein-Friesian cows scored in cubicles from 2000 to 2006.

Lastly, chapter 7 contains general discussion and recommendations.

CHAPTER 2
LITERATURE REVIEW

2.1 Lameness Assessment

Lameness in dairy cows has been described as any abnormality that causes the cow to change its gait (Defra, 2007), and this change in mobility is measured by locomotion scoring. Locomotion scoring refers to a subjective assessment of the cow's walking ability which is usually done on a level surface. Studies have reported high genetic correlation between lameness and locomotion scoring (Boelling, 1999; Stott *et al.*, 2005). Thus, locomotion score gives information on the degree of lameness. There exits a plethora of locomotion scoring systems for dairy cows in use by researchers. Manson and leaver (1988) devised a 5 point system with quarterly intervals Table (2.1). Although this system is commonly used by researchers (Whay, 2002), it presents two main problems- subjectivity and complexity (Ward, 1998). Based on this, simpler and less complex scoring systems were developed by several researchers (Tranter and Morris, 1991; Wells *et al.*, 1993; Whay *et al.*, 1997; Sprecher *et al.*, 1997).

Table 2.1 Locomotion scoring system developed by Manson and Leaver (1988)

Score	Description
1.0	Minimal abduction/adduction, no unevenness of gait, no tenderness.
1.5	Slight abduction/adduction, no unevenness or tenderness.
2.0	Abduction/adduction present, uneven gait, perhaps tender.
2.5	Abduction/adduction present, uneven gait, tenderness of feet.
3.0	Slight lameness, not affecting behaviour.
3.5	Obvious lameness, some difficulty in turning, not affecting behaviour.
4.0	Obvious lameness, difficulty in turning, behaviour pattern affected.
4.5	Extreme difficulty in rising, difficulty in walking, behaviour pattern affected.
5.0	Extreme difficulty in rising, difficulty in walking, adverse effects on behaviour pattern.

Boelling and Pollott (1998a) used the above system and described a 9 point locomotion scoring system (Table 4.2) from 1 (lame) to 9 (sound locomotion). Generally, cows with score 1 – 4 are regarded as lame while those with score 5 – 9 are considered as having sound locomotion. This locomotion scoring system is being used to score the UK national herds and has been employed in major parts of this thesis. According to Whay (2002), the key to selecting an appropriate scoring system is to choose one that is easy to use and that is also efficient and concise in data collection. This is specifically important at the farm level where farmers rather than trained professionals undertake lameness scoring, at least to identify lame cows requiring treatment. The locomotion scoring system used in chapter 3 of this thesis (Table 3.1) was devised from Manson and Leaver (1988) to fulfil the above purpose.

2.2 Factors Associated with Lameness

Lameness in dairy cows is a multifactorial defect comprising several disorders and caused by both genetic and environmental factors.

2.2.1 Genetic Influences

Abnormalities in leg and feet conformation are heritable and have been associated with increased incidence of lameness. Boelling (1999) reported that cattle having more sickled legs and a shallow foot angle had an increased risk of lameness incidence. In corroboration, Brotherstone (2005, unpublished) estimated a moderate genetic correlation (0.43, -0.59) between locomotion, foot angle and rear leg side view, respectively and concluded that locomotion problems are associated with low foot angle and sickled legs. van der Waaij *et al*. (2005) analysed 8 claw disorders (digital dermatitis, interdigital dermatitis/heel horn erosion, sole heamorrhage, chronic laminitis, sole ulcer, white line disease, interdigital hyperplasia and interdigital phlegmon) and 5 leg and feet conformation traits (rear leg rear view, rear leg side view, foot angle, locomotion and leg and feet composite) on 21,611 Dutch dairy cows and concluded that the genetic correlations between the disorders and the conformation traits were generally high, although some were not significantly different from zero. In another study, Ral *et al*. (1995) reported a genetic correlation of 0.49 and 0.58 between heel depth, interdigital dermatitis and heel erosion, respectively indicating that cows with low heel depth are susceptible to these deformaties.

It has also been shown that daughters of some bulls were more likely to suffer claw lameness than those of other bulls, and as such it would be sensible to consider clinical lameness when selecting bulls for breeding (Russell, 1987). Boettcher *et al*. (1998)

estimated the heritability of lameness as 0.10 and 0.22 from linear and threshold models. Boelling (1996) obtained 0.10 as a heritability estimate for lameness in first lactation dairy cows. There has also been indications that certain breeds are more predisposed to lameness than others. In the UK, Peterse (1985) mentioned that the hooves of Friesians were more prone to damage than those of Jersey and Shorthorn cattle. Harris *et al*. (1988) also noted that Friesian herds had increased incidence of lameness compared to Jersey-Friesian crossbred herds. Under extensive production systems, sole ulcers occurred predominantly in very large framed Holstein-Friesian cows (Jubb and Malmo,1991), suggesting a strong susceptibility.

2.2.2 Environmental Factors

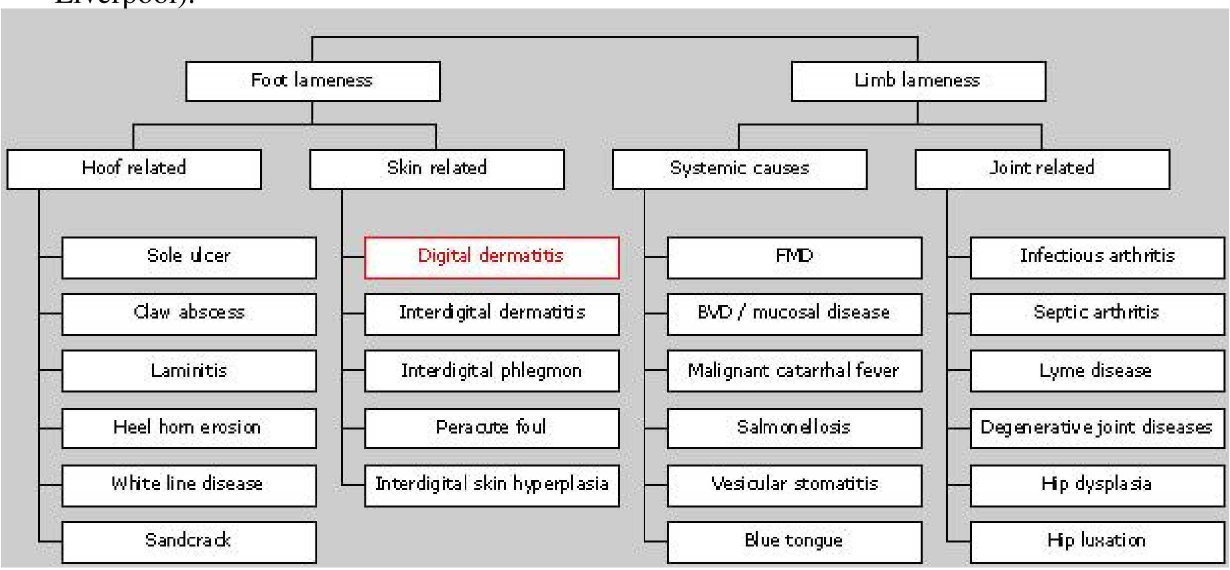
Apart from genetic effects, environmental factors also influence legs and feet traits. Diet, housing and general management of dairy herds all affect the health of legs and feet. Some researchers have reported higher rates of lameness in loose housing systems than in tie stalls (Bergsten and Herlin, 1996; Manske *et al*., 2002; Cook, 2003). A significantly higher incidence of leg injuries on the hock was reported for cows housed in free stalls with mats compared with those on free stalls bedded with straw (Wechsler *et al*., 2000). According to Stefanowska *et al*. (2001), floor type is one of the most critical aspects of loose housing systems because of its effect on cow locomotion. Greenough and Vermunt (1991) noted that standing on concrete was a risk factor for lameness. Bergsten and Frank (1996) reported that hardiness, abbrassiveness and slippery features of concrete floors contribute to foot lesions and lameness. Reports from Frankena *et al*. (1992) and Raven (1992) agreed that the incidence of legs and feet disorders increased as cows spend more time on concrete and were exposed to a relatively moist environment.

Somers *et al*. (2003) investigating the prevalence of claw disorders in cows exposed to several floor systems noted that all herds on concrete flooring (slatted floor, slatted floor with manure scraper, solid concrete floor and zero-grazing) were infected by DD, resulting in an average cow level prevalence of 30%. In another study, Somers *et al*. (2005) reported an increased risk of digital dermatitis for cows housed on solid concrete floors, compared with those on slatted floors with or without automatic scrapers. The authors also found that cows with restricted or zero grazing had an increased risk of digital dermatitis compared with those at pasture, possibly due to a high exposure to disease-causing organisms in slurry. Herlin and Drevemo (1997) also observed that zero-grazing of cows in cubicles had a negative effect on locomotion in comparison with seasonal grazing. A number of studies have reported decreased cases of hoof disorders and lameness for cows at pasture compared to cows in other housing systems.

2.2.3 Hoof Diseases

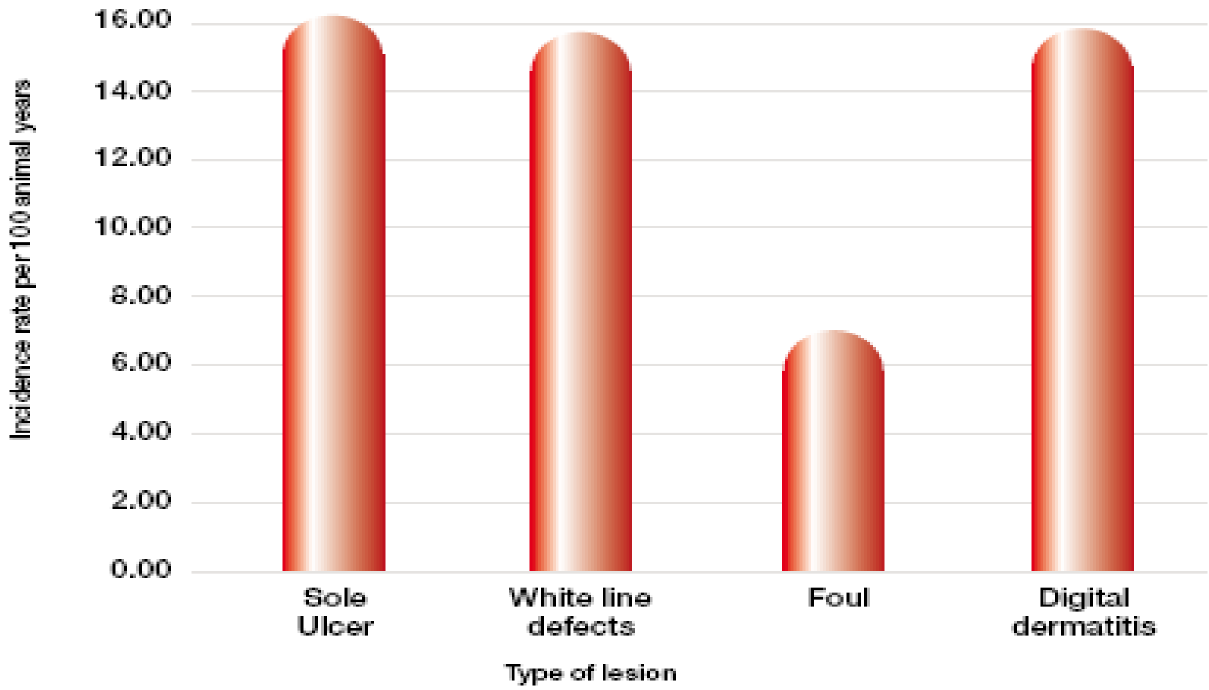
Several hoof disorders which result in pain and discomfort have been associated with lameness. Murray *et al*. (1996) reported that over 90% of lameness in dairy cows results from hoof lesions. Clarkson *et al*. (1996) corroborated this fact by reporting that claw horn lesions (79%) are the most common cause of lameness. These disorders are shown in Figure 2.1. However, in this review diseases of the hoof will be restricted to digital dermatitis.

Figure 2.1 Classification of diseases resulting to lameness in cattle (University of Liverpool).



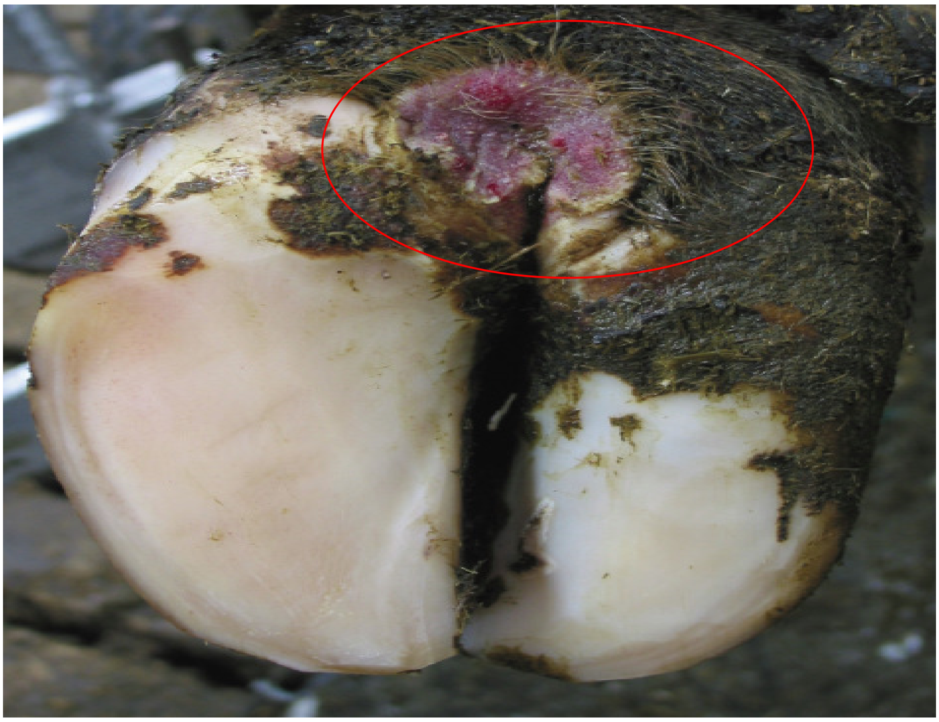
Bell (2004) observed that the 3 most common hoof pathologies were sole and white lesions, heel erosion and dermatitis. In an intervention study involving five herds and a total of 1,109 cows (Hedges *et al*., 2001), the incidence of DD was around 12 cases per 100 cows per year and was ranked equal to sole ulcers and white line defects as a cause of lameness (Figure 2.2). From a portal survey of the incidence of lameness and claw lesions in dairy cattle in the UK, Amory *et al*. (2004) reported that, at 16%, digital dermatitis was the third most common cause of hoof lesions in cows, after sole ulcer (27%) and white line disease (20%).

Figure 2.2 Incidence rate of four most common causes of lameness (Hedges *et al*., 2001). Adapted from Blowey (2007).



Digital dermatitis was first described internationally in 1974 and in the UK in 1987. Since then it has become wide spread throughout the country (Blowey, 2007). DD is an infectious skin disease affecting basically the area directly behind the heels and between the digits. Early lesions produce matting of the hairs, which stand erect in thick light brown exudates with a characteristic pungent odour (Blowey *et al*., 1994). Figure 2.3 indicates a typical DD lesion.

Figure 2.3 A typical digital dermatitis lesion



Digital dermatitis lesions cause severe lameness and thus have negative consequences on the general well being of dairy cows (Blowey and Sharp, 1988; Rodriguez-Lainz *et al*., 1996; Greenough and Weaver, 1997). DD is very painful to the cow resulting in reduced mobility and feed intake. Consequently, DD has also been associated with decreased milk yield, reduced reproductive performance and an increased culling rate in affected cows. In addition, the treatment costs associated with DD may lead to adverse financial losses to affected producers (Nutter and Moffit, 1990; Read and Walker, 1994; Argaez-Rodriguez *et al*., 1997).

A study conducted by the National Animal Health Monitoring Systems involving 83% of US dairy cows in 20 states observed that 43.5% of the dairy herds had cows that showed signs of clinical DD with variation in herd size and region (Wells *et al*., 1999). The same study reported that the average percentage of cows affected was 18.9%, with a high percentage of the DD affected cows (81.9% of cows and 85.9% of heifers) becoming lame. In the UK, DD occurs in over 70% of herds and accounts for up to 25% of all lameness cases in dairy cattle (ADAS, 2001). However, the incidence of the disorder can vary from farm to farm.

According to Brydl *et al*. (2004) DD usually responds to treatment with a range of broad spectrum antibotics (lincomycin, oxytetracycline) but most commonly recurs in the same lactation (Kofler, 1998; Webster, 2002). In line with this, Demirkan *et al*., (1999) noted that the aetiopathology of DD is unclear and hence control measures are largely ineffective. Again, Murray *et al*. (2002) stated that treatment and control of DD is expensive in terms of time and labour, and there is presently concern that disposal of footbath solutions used for treatment may pollute the environment. This gives credence to genetic selection of cows for resistance to DD as an additional, and possibly better, means of reducing the incidence in herds. Research has indicated that DD is heritable and genetically correlated to leg conformation traits (Koenig *et al*., 2005; van der Waaij *et al*., 2005).

2.3 Association between Lameness and Milk Yield

The prevalence of lameness in dairy cows has been estimated at 15% in the USA (Wells *et al*., 1999) and 22% in England (Whay *et al*., 2002). Considering this high lameness prevalence in dairy cows, the association between lameness and milk yield is of huge economic importance. Several studies have tested the impact of lameness on milk yield and noted varied results. Some of these studies indicated that high yielding dairy cows are at a greater risk of lameness (Dohoo and Martin, 1984; Rowlands and Lucey, 1986; Barkema *et al*., 1994; Green *et al*., 2002). However, Grohn *et al*. (1995) ascribed that high yielding cows are not necessarily more susceptible to disease provided nutrition and husbandry meet their increased biological needs. Lame cows were reported to produce lower milk than their unaffected counterparts (Tranter and Morris, 1991; Warnick *et al*., 2001; Hernandez *et al*., 2002), their potential (Green *et al*., 2002) and as predicted (Rowlands and Lucey, 1986). The estimated loss of milk yield per cow has been given as 1.5 kg/day two weeks after diagnosis (Warnick *et al*., 2001), 1.5-2.8 kg/day two weeks after diagnosis (Rajala-Schultz *et al*., 1999), up to 2 kg/day for up to 5 months before and after diagnosis or 350 kg/305-d lactation (Green *et al*., 2002). Milk losses have also been associated with lesion-specific causes of lameness. Warnick *et al*. (2001) reported that lame cows with sole ulcers had the greatest loss of milk, followed by sole and white line abscesses and interdigital phlegmon. In another study, Hernandez *et al*. (2002) observed that cows that were lame with interdigital phlegmon produced less milk (7767 kg) than unaffected cows (8622 kg). Amory *et al*. (2008) recorded approximately 370 and 570 kg milk loss per lactation in lame cows with white line disease and sole ulcer, respectively. Earlier, Nutter and Moffit (1990) estimated the loss of milk production due to digital dermatitis at 57 litres/cow/lactation under UK conditions. Sogstad *et al*. (2007) also observed that cows with dermatitis yielded less milk than those without the defect.

Conversely, other studies have reported an increase in the milk yield of lame cows (Dohoo and Martin, 1984; Barkema *et al*., 1994). Barkema *et al*. (1994) observed an increase in 100-d cumulative milk volume for cows with any cause of lameness. They also reported an increased milk yield from 100 to 270 DIM in the same lactation in cows with sole ulcer. Another study recorded higher milk yield in cows with lesions at the tarsus, heel horn erosion, and hemorrhages of the white line and the sole than in cows without these lesions.

The reports of increased milk production among lame cows sparked an argument among researchers as to whether or not high milk production is associated with the occurrence of lameness. A number of studies have investigated this relationship (Rowlands and Lucey 1986; Deluyker *et al*., 1991; Barkema *et al*., 1994). From their studies, the relationship between high milk production and lameness supports the possibility that high milk production is a risk factor for lameness. Other studies also reported higher levels of lameness in herds with higher milk production (Enevoldsen *et al*., 1991a,b), but recent studies have found no such association (Vaarst *et al*., 1998; Whitaker *et al*., 2000; Haskell *et al*., 2006). This could mean that high milk production per se may not lead to lameness if other factors such as management and nutrition are adequate.

Other research work has also found no relationship between average milk yield and lameness (Cobo-Abreu *et al*., 1979; Aeberhard *et al*., 2001). Warnick *et al*. (2001) reported no significant effect of digital dermatitis on milk yield. These discrepancies on the association between milk yield and lameness have been attributed to the use of different measures of milk production, different definitions for lameness, culling bias, variation in herd management and use of different statistical method of analysis (Warnick *et al*., 2001). Based on these discrepancies, Barkema *et al*. (1994) suggested that when the impact of lameness on milk production is being assessed an estimate of milk loss should be calculated as a deviation from the lactation curve daily yields. This was supported by Sogstad *et al*. (2007) by stating that lactation curves allow surveillance of milk production throughout the lactation and detection of exact times of decreases in milk yield.

2.4 Influence of Lameness on Fertility

Fertility, defined by Darwash *et al*. (1997) as "the ability of the animal to conceive and maintain pregnancy if served at the appropriate time in relation to ovulation", has a substantial economic value with regard to herd production and profitability. The association between lameness and reproductive performance has been established by various studies. Weaver (1988) opined that lameness could be a possible cause of reduced fertility as lame cows spend more time lying down, show less standing estrus and compete poorly for available feed. In a study involving 17 dairy farms and 427 lameness cases in the UK, Collick *et al*. (1989) reported that lameness (occuring before 120 days after calving) was significantly associated with increased calving-to-conception interval. Sprecher *et al*. (1997) developed a locomotion scoring system to monitor lameness and predict future reproductive performance. From the study, they observed that lame cows were 15.6 times more likely to have an increased interval for days open compared to the mean days open for healthy cows. Garbarino *et al*. (2004) investigated the effect of lameness on ovarian activity in postpartum Holstein cows and concluded that lame cows had 3.5 times greater odds of delayed cyclicity. Based on their studies, they suggested that delayed ovarian cyclicity in lame cows would be reduced by 71%, if lameness is prevented. These findings show that lameness has a detrimental effect on the reproductive performance of the dairy cow.

In another study, Hernandez *et al*. (2001) reported that claw lesions were the main cause of lameness and impaired fertility, as shown by a higher incidence of lame cows, a longer calving-to-conception interval (140 days) and an increased number of services per conception (5) compared to healthy cows (100 days and 3 services, respectively). Sole ulceration was significantly ($P < 0.05$) associated with an increase of 11 days from calving to first service compared to unaffected cows (Collick *et al*., 1989). Moderate and severe heel horn erosions in first lactation cows were associated with increased calving interval (Sogstad *et al*., 2006). Using a commercial Mexican dairy herd, Argaez-Rodriguez *et al*. (1997) noted a significantly ($P < 0.01$) longer calving-to-conception interval (113 days) in cows with digital dermatitis compared to non-defective cows which had a 93 day interval. The impact of lameness, in particular lesion-specific causes of lameness, on fertility is not well documented in the literature.

2.5 Lameness and Longevity

Dairy cow longevity is important as a result of its influence on herd productivity and hence profit. Stott (1994) considered the economic advantage of longevity in dairy cows and concluded that increased longevity could add about £20 per extra lactation to the profitability of the replacement dairy heifer. Stott *et al*. (2005) gave this figure at £30 per lactation. The average productive life of dairy cows is three to four lactations (Strandberg, 1996), but most cows are culled involuntarily for different reasons which lowers their lifetime productive efficiency in herds. Lameness is associated with decreased longevity through an increased culling rate due to the disorder and its effect on production and reproductive efficiency. Lameness has been given as a major reason for premature culling after poor fertility and mastitis. In a survey of 50 Holstein-Friesian dairy herds in the UK, lameness was indicated as the reason for culling 5.6% of cows (Esslemont and Kossaibati, 1997). In other studies involving 17 British (Collick *et al*., 1989) and 13 Dutch (Barkema *et al*., 1994) dairy herds, lameness accounted for 10% and 9% culling of cows, respectively. Rajala-Schultz and Grohn (1999) found a significant culling effect throughout the entire lactation period, although the risk was greatest during the first half of lactation. Corroborating this fact, Booth *et al*. (2004) noted that lame cows were generally at a greater or equal but never at a reduced risk of being culled compared to healthy cows.

Researchers have found favourable genetic correlation between longevity and type traits, and noted type traits as good predictors of longevity (Brotherstone and Hill, 1991a, b; Boldman *et al*., 1992). Dadpasand *et al*. (2008) reported that extreme scores for udder depth, rear legs, side view and foot angle increased the risk of culling in an Iranian Holstein herd. Estimates of genetic correlations between disease and survival for clinical mastitis and leg and feet problems were given as 0.52 and 0.43, respectively (Ulrik *et al*., 1999). These correlations suggest that health traits, including leg and feet problems, are good indicators of involuntary culling. In an earlier study, Uribe *et al*. (1995) reported that culling for leg problems was more a problem in high yielding cows as the genetic correlations between leg problems and milk, fat and protein (0.27, 0.20 and 0.21, respectively) were unfavourable. The association between longevity and diseases of the hoof e.g digital dermatitis is not well documented in the literature.

CHAPTER 3

RISK FACTORS AND MILK YIELD LOSSES ASSOCIATED WITH LAMENESS IN HOLSTEIN-FRIESIAN DAIRY CATTLE

3.1 Summary

Weekly locomotion scores on a scale of 1 to 5 were used to investigate the relationship between cattle lameness, management systems and the impact of lameness on milk production. The data were 14,026 locomotion scores from 248 Holstein-Friesian cows. Cows were managed in two groups, XE (high-concentrate feed and housed indoors all year) and XM (low-concentrate feed and outdoors in summer). Analysis was performed using residual maximum likelihood. Results indicated that the most significant variables affecting locomotion were time of year when the animal was locomotion scored and management group. Cows scored during February and August had increased locomotion problems. Cows in the more intensively managed group had significantly poorer locomotion compared with those in the more extensive group. Older animals were more susceptible to lameness than heifers. Body weight, body condition score and days in milk (DIM) also accounted for significant variation in locomotion score. Poor locomotion was associated with a significant reduction in the milk yield of later lactation cows. There was a significant difference in the shape of the lactation curve depending on whether or not the cow was lame during lactation. Average persistency was greater for the group of cows never lame throughout lactation compared with those lame before 60 DIM.

3.2 Introduction

Lameness in dairy cattle is a continuing problem that greatly affects the welfare of the animals (Farm Animal Welfare Council, 1997) and causes reduced productivity and poor performance (Warnick *et al*., 1995). Several factors that affect dairy cattle lameness have been suggested. Housing environment (e.g. pasture, concrete floors) has been found to be significantly associated with locomotive problems (Gitau *et al*., 1996; Somers *et al*., 2003), and both time of year and time post calving have been shown to affect lesion formation and locomotion (Offer *et al*., 2000; MacCallum *et al*., 2002). Body weight (BW) reflects changes in size and shape of animals over time (Monsi, 1992), and may affect locomotion negatively. Singh *et al*. (1993) showed that lame cows lay down for longer periods than healthy cows and so consumed less food. Even when grazing, lame cows tended to lay down for longer and ate for shorter periods than healthy cows.

Reports on the effect of lameness on milk production levels of cows have varied among researchers. Green *et al*. (2002) analysed test-day yields from 900 cows on five farms and estimated a 360 kg reduction in milk yield per 305-day lactation. Warnick *et al*. (1995) observed that milk yield was reduced for up to 2 weeks before lameness was recognised, perhaps resulting from reduced intakes and negative energy balance. Other authors have reported an increase in milk yield (Barkema *et al*., 1994) and no change in milk yield (Martin *et al*., 1982).

A UK governmental study (Lobley *et al*., 2001) concluded that many livestock areas will show further polarization between intensively managed dairy farms and more extensive enterprises. Larger dairy farms will expand and intensify while smaller farms will move to more extensive systems. Intensive dairy farms are characterised by high yielding cows fed high levels of concentrates and housed indoors much (if not all) of the year. The genetic correlation between production and health traits is generally unfavourable (Pryce *et al*., 1998) and selection for yield has resulted in increased mastitis, fertility problems and lameness. Research into the effects of intensive management on health traits is not well documented but, with the increase in high-input farming systems, is an area that requires monitoring.

3.3 Objectives

The aims of this study are (1) to examine the functional relationship between locomotion score and explanatory variables such as management regime, (2) to evaluate the association between daily milk yield and locomotion score and (3) to investigate the effect of lameness on the shape of the lactation curve.

3.4 Material and Methods

3.4.1 Data

The data used in this analysis were collected from the Langhill herd at Crichton Royal Farm in Dumfriesshire, Scotland between 2003 and 2005. The herd comprised two genetic groups: control (C) (daughters of average bulls in the UK for fat plus protein yields) and selected (S) (daughters of highest ranking bulls in the UK for fat plus protein yields).

Cows were randomly allocated to two management regimes, XE (housed all year round and fed a high-concentrate and low-forage diet) and XM (cows allowed to graze from April to October and receiving at least 75% diet DM from forage), at first calving and they remained on the same regime until they were culled or removed from the experiment. Cows calved all year round.

Data were obtained from five lactations. Incidence of lameness on the farm was described using a locomotion scoring technique shown in Table 3.1. The method is based on the system of Manson and Leaver (1988), and uses a 5-point scale, where a 1-point score depicts sound (normal) and 5 reflects difficulty in turning. Each cow had multiple records depending on how often she was locomotion scored. Animals in the study herd calved between 22 (1^{st} lactation) and 84 (5^{th} lactation) months of age (age at calving) and were within 1 and 350 days in milk (DIM). Three trained technicians undertook both locomotion scoring and body condition scoring (BCS) weekly. All cows were locomotion scored as they left the milking parlour, i.e. on the same surface. BCS was recorded on a standard subjective scale of 0 to 5 with quarterly increments (Lowman *et al.*, 1976). Maximum BCS recorded for cows was 4. The cows were milked three times per day and each cow was weighed as she left the milking parlour. Weights were expressed as a daily average.

Data were edited to remove extraneous observations or cows with extreme recordings (±4 standard deviations from the mean). Month of scoring was taken from date of recording, likewise month of calving from date of calving (both calendar months). After editing, 14, 026 locomotion records and 98, 651 daily milk yield records on 248 cows remained.

3.4.2 Statistical Analysis

3.4.2.1 Locomotion Study. Cows were grouped into 1st lactation cows and later lactation cows (2nd, 3rd, 4th and 5th lactation) as there were few 3rd (106), 4th (54) and 5th (20) lactation animals. There were 163 1st lactation cows, 73 in group XM and 90 in group XE; 79 in group S and 84 in group C. The later lactation group comprised 180 cows and 313 cow lactations. There were 95 later lactation cows in group XM and 85 in group XE; 84 in group S and 96 in group C. First lactation cows and later lactation cows were analysed separately.

The statistical model is

$$Y_{ijk} = \mu + F_i + C_{ij} + e_{ijk}$$

where

Y_{ijk} = k^{th} locomotion score (1 to 5) on the j^{th} cow with i^{th} fixed factors and covariate measurements; μ = mean; F_i = effect of i^{th} fixed factors – month of locomotion scoring, month of calving (MOC), management group, management group x month of scoring interaction, genetic group, year of inspection, lactation number (for cows only), technician undertaking the scoring and i^{th} linear and quadratic covariates – BCS, BW, age at calving; C_{ij} = random effect of cow; e_{ijk} = residual random error.

In addition, in the analysis of later lactation cows, a cow lactation random term was included in the model to account for repeatability across lactations. The order of fitting of variables was varied (each after all others) so that F-statistics were conditional on all other effects in the model. Including cow identity as a random effect in the model linked all observations on each cow. The analysis described above includes month of locomotion scoring and month of calving as fixed effects but the results do not explicitly give information on the association between the time from calving (i.e. DIM) and the locomotion score. To address this, and avoid any problems with aliasing, the analysis was repeated excluding month of locomotion scoring from the model and including DIM as a linear and quadratic covariate. A further analysis allowed the regression of locomotion score on DIM to vary depending on the month of calving. All analyses were performed using residual maximum likelihood (REML) in the software package R (Venables *et al.*, 2005).

3.4.2.2 Milk Yield Analysis. The objective in this analysis was to evaluate the association between milk production of heifers and cows and locomotion score. The trait, therefore, was daily milk yield. The basic model of analysis was as above, but excluded classifier and month of locomotion scoring. In addition to other variables, DIM (as a 3rd order polynomial), locomotion score, month of milk recording, management group x month of calving interaction and interactions between locomotion score and both management group and genetic group were included in the model.

3.4.2.3 Analysis of 'Lame or Never Lame' Cows. A further investigation examined differences in the shape of the lactation curves of cows that were scored lame during the lactation and those judged never lame. For the purpose of this analysis, cows locomotion scored 1 or 2 were considered sound (never lame) while those scored 3, 4 or 5 were classified as lame. Lame cows were grouped into those that became lame on or before 60 DIM (i.e. before the time of peak yield) and those that became lame after 60 DIM. For this analysis I used the same model as for the analysis of milk yield but fitted a separate lactation curve for each group of cows. This analysis allowed me to statistically compare curve coefficients across groups. A similar analysis was not performed for heifers because a preliminary analysis indicated no significant variation in their milk yield due to locomotion score.

3.5 Results

3.5.1 Locomotion Study

Locomotion score was assumed normally distributed and analysed using a simple linear mixed model. Although residuals were not perfectly normally distributed (slightly skewed and leptokurtic), they did not deviate sufficiently from normal to justify a more sophisticated analysis.

The average locomotion score for the herd was 2.04. Only 11% of the cows in the herd were lame at any point during the lactation, i.e. scored ≥3. For lactation 1 animals, locomotion scores ranged from 1 to 4, with 82 heifers being scored 3 at least once and 70 receiving at least one score of 4. For later lactation cows, locomotion scores ranged from 1 to 5, although only four cows (each with many scores of 4) were locomotion scored 5. There were 117 cows with at least one score of 3 and 110 with one or more locomotion scores of 4.

Figure 3.1 shows the fitted lameness values by month of locomotion scoring for heifers and cows. Solutions for month of locomotion scoring are relative to January. Month of scoring was significantly ($P < 0.001$) associated with the locomotion of heifers and cows in a similar pattern. However, the graph shows that later lactation cows were more susceptible to increased locomotion disorders than heifers. After adjusting for management group, winter and summer months were the highest risk periods with peak rise in herd lameness occurring in February and August. Mid to late spring (months 3 to 4) were the safest period. There was a steady but slow increase in lameness incidence from mid autumn through the winter months. Table 3.2 shows the least square estimates for locomotion score for both heifers and cows.

There was a significant ($P < 0.001$) linear association between BW and the locomotion of cows in later lactation. The estimated effect was negative (a linear regression coefficient of -0.14 for a 100 kg difference in BW), indicating that a lower BW was associated with increased locomotive problems. The condition score of both heifers and cows was significantly associated with their locomotion score. Animals with a higher body condition had higher locomotion scores. No significant association between locomotion score and parity was detected.

There was a significant association between management group and the locomotion of both heifers and cows and management group x month of scoring interaction was also significant for all animals. Cows in the XE group (housed all year and fed a high concentrate + low-forage diet) suffered an increase in lameness compared with those in group XM (at grass in the summer months and fed low concentrate + high forage). Figure 3.2a and b show average locomotion score by month of locomotion scoring for heifers and cows in both management groups. It is clear that, irrespective of when the animals were locomotion scored, heifers and cows in the XE group had a higher mean locomotion score than those in the XM group, and this difference varied depending on the time of year of scoring. During early summer, lameness decreased in the animals turned out to graze, whereas in summer lameness was at a higher level for heifers and cows housed all year round.

When month of locomotion scoring was replaced by DIM in the model, there was a significant association between time post calving and locomotion for both heifers ($P < 0.05$) and cows ($P < 0.001$). These associations were linear, indicating that locomotive problems increased with DIM. However, repeating the analysis and allowing the linear and quadratic coefficients to vary depending on the month of calving indicated that the relationship between locomotive problems and DIM varied depending on the month of calving. For calvings from December to April, locomotive problems were, in general, at a minimum in mid-lactation (i.e. during summer), whereas for summer and autumn calvings the incidence of locomotive problems increased with DIM.

In all analyses the cow variance component and the cow lactation variance component were significantly different from zero, indicating repeatability of locomotion problems within lactation (for both heifers and cows) and across lactations (cows).

3.5.2. Milk Yield Analysis

Month of calving and its interaction with the management group removed significant variation in the milk of both heifers and cows. For heifers, no significant associations were detected with age at calving, locomotion score and interactions between locomotion score and management group and locomotion score and genetic group. For cows, there was no significant association between parity and yield. All other variables included in the models were statistically significant. Results (Table 3.3) showed a quadratic association between BW and yield, with heavier animals producing more milk. Similarly, a quadratic association between BCS and milk yield was observed for both heifers and cows, with very thin animals and fatter animals producing less milk. For cows, a locomotion score of 4 was associated with a 0.78 kg loss in daily milk yield compared with cows scored 1. The association between locomotion score and milk yield varied depending on the management group and the genetic group.

Management group XM was associated with a lower milk production, compared with group XE (the high-concentrate group). Differences between management groups were 4.1 and 6.0 kg for heifers and cows, respectively.

As expected, this study recorded lower milk production in the control genetic group than in the select genetic group. Select heifers produced approximately 3.6 kg more milk daily than the control heifers while select cows in later lactation gave 6.5 kg/day higher milk yield compared with the control cows.

3.5.3 Analysis of ‘Lame or Never Lame’

There were no significant differences in the average 305-day yield of cows never lame, those lame before day 60 and those lame after day 60. Results (Figure 3.3) indicate that the group of cows that was lame early in lactation had a higher average milk yield during the first few weeks of lactation than cows never lame or those lame after day 60. A significant difference (t-test, $P<0.001$) in the quadratic coefficient was found for the lactation curves of sound cows and those lame before 60 DIM. There were significant differences ($P<0.05$) in the linear, quadratic and cubic coefficients of cows never lame and those lame after day 60. In addition, there was a significant difference ($P<0.05$) in the linear coefficients of cows lame before day 60 and those lame after day 60. These differences in curve coefficients indicate that the shape of the lactation curves differed statistically between the three groups of cows.

If I define persistency as the ratio of the average yield on day 280 to the average yield on day 60, the persistency of sound cows was higher (58%) than that of cows lame before day 60 (55%).

3.6 Discussion

3.6.1. Locomotion Study

This study considered locomotion score rather than the more usual lameness recording. Lameness is typically recorded on a present or absent basis, with the threshold between these two outcomes somewhat subjectively defined. Locomotion scoring gives additional information on the gait of the animals and can identify varying degrees of lameness and provide an indication of the presence and severity of foot problems.

The range in locomotion scores was 1 to 4 for the heifers and 1 to 5 for cows. In essence, no heifer was severely lame. Hirst *et al*. (2002) noted a steady increase in lameness with parity up to lactation 6, when the relationship began to level off. Increased clinical lameness as cows age has also been noted by Boettcher *et al*. (1998), and Pötzsch *et al*.

(2003) found that white line disease lameness increased with increasing parity. I was, however, unable to detect significant differences in the locomotion scores of later lactation animals (parities 2 to 5). This is probably due to the small number of animals in each parity and the low proportion of lame and severely lame cows in my data. Cows in management group XE were more prone to locomotive problems than those in XM. There are two main reasons for this. Firstly, cows in XE were housed all year round. In general, cows kept on pasture are likely to suffer fewer locomotion problems than those housed indoors (Gitau *et al*., 1996; Somers *et al*., 2003). Secondly, this group was fed higher levels of concentrate to support their higher milk yield. This has been associated with increased levels of lameness (Kelly and Leaver, 1990; Livesey *et al*., 1998). However, the effect of nutrition on levels of lameness is equivocal, as several studies have failed to show significant effects of feeding and suggest that increased lameness results from an interaction of several risk factors (calving, housing, metabolic and environmental challenges) (Bergsten and Frank, 1996; Olsson *et al*., 1998).

For both heifers and cows in group XM, locomotive problems were fewest during early summer but increased in August. According to a staff at Crichton Royal Farm (oral communication), this could be due to farm tracks becoming firmer and cows having longer walks to more distant fields.

For both heifers and cows in group XE, locomotive problems were greatest in February and in the summer months, possibly due to the effect of continuous housing, high-concentrate feeding and changes in the support structure of the hooves associated with calving (Tarlton *et al*., 2002).

The association between BW and locomotion problems is not well documented. Webster (2001) studied the development of lesions in heifers and concluded that there was no association between lesion scores and BW. The results obtained in this study indicate that cows that were lame were also lighter in weight, possibly due to a reduction in appetite.

Many researchers report a significant association between DIM and lameness. Offer *et al*. (2000) found significant effects of DIM on lesion formation, claw conformation and heel erosion. Tranter and Morris (1991) noted that cases of lameness increased until around 100 DIM, then decreased, whereas Boettcher *et al*. (1998) and Green *et al*. (2002) reported that lameness was more common during early lactation. This analysis shows that both DIM and month of calving (or DIM and month of inspection) should be considered when examining the association between lameness and stage of lactation as this association may vary depending on the month of calving or the month of inspection.

3.6.2. Milk Yield Analysis

Locomotion problems were associated with decreased milk production of cows in lactation 2 to 5, evidence that these problems may adversely affect milk production. A lame cow (locomotion score 4) was associated with an average loss of 0.78 kg of daily milk yield compared with a sound cow (locomotion score 1). Similarly, a locomotion score of 5 was associated with a reduction in milk yield of 5.5 kg. Note, though, that the high standard error of this estimate meant it was statistically not different from zero. This association between locomotion disorders and reduced milk yield is consistent with the results from other studies. An economic analysis of data from 21 Dutch dairy farms estimated that cows culled for lameness had 3.3 kg/day lower milk production than other cows (Enting *et al*., 1997). Rajala-Schultz *et al*. (1999) estimated 1.5 to 2.8 kg/day milk losses within 2 weeks after veterinary-diagnosed lameness in Finnish dairy cows. More recently, Green *et al*. (2002) concluded that lame cows have been higher producers that are failing to produce rather than cows that produce less milk.

Very low BCS and increased BCS were associated with decreased milk production in this analysis. BCS is measured independently of BW and frame size; thus, it is a reflection of the degree of subcutaneous fat deposition in the body. The rate of utilisation of this fat during lactation affects milk yield. No heifer or cow was considered obese (BCS = 5) by the scorer but some cows were thin (BCS = 1). Coffey *et al*. (2002) showed clearly that reduction in BCS as lactation progresses is less severe in heifers than later lactation cows, and is commensurate with the lower yield, feed intake and live weight exhibited by 1st lactation cows. A higher milk loss in relation to BCS was recorded for cows than for heifers. This may be due to successive lactations resulting in the substantive rapid depletion of body fat and protein reserves, and subsequently influencing milk yield.

3.6.3. 'Lame or Never Lame' Cows

The lactation yield of cows that were never lame was not significantly different from the yield of cows lame before day 60. However, the initial yield of cows lame before day 60 was higher than the yield of never-lame cows. This higher yield declined after the first quarter of lactation, indicating that high-yielding cows fail to sustain their high production capacity throughout lactation as a result of locomotion problems. Hence, profit would be greatest for cows that were never lame. The lactation yield of cows lame after day 60 was greater than the yield of cows that were never lame (difference of 214 kg; s.e. = 211), although this difference was not statistically significant. This does not advocate selection for cows with poor feet and legs but indicates that higher levels of milk production are associated with higher levels of locomotion problems. Deluyker *et al*. (1991) also reported higher levels of lameness in herds with higher levels of milk production. High milk yield has also been associated with high levels of mastitis (Waage *et al*., 1998), poor fertility and reduced longevity (Collard *et al*., 2000; Wathes and Taylor, 2002), stressing the need for inclusion of health-and welfare-related traits as well as production traits in selection indices for herd improvement.

The group of cows recorded as sound throughout lactation had a higher persistency than those lame before day 60. Other researchers have also reported favourable associations between persistency and health. Harder *et al*. (2006) estimated approximate genetic correlations between persistency of milk yield and claw and leg diseases in the range -0.13 to -0.46, and concluded that good persistency is associated with fewer claw and leg diseases.

Muir *et al*. (2004) estimated genetic relationships between lactation persistency and reproductive performance and concluded that selection for persistency has merit for genetically improving heifer reproductive performance.

The animals used in this study are part of a research herd. The main aim of the research at the farm is to develop sustainable breeding systems with particular emphasis on improving health and welfare. The locomotion scoring system at the farm was designed to be simple and effective so that as many farmers as possible would adopt it.

However, the herd is a commercial herd and is managed in a profitable manner. Although management practices are good, there is no reason to suppose that results from this study cannot be applied to the general dairy cattle population.

3.7 Conclusions

This analysis has shown that the most important variables influencing locomotion in heifers and cows are management regime and time of year when locomotion scoring takes place. Cows housed all year and fed a high-concentrate diet are more prone to locomotive problems than those managed in a more extensive system. The difference is most obvious during the grazing season. A significant relationship between decreased BW of lactation 2 to 5 cows and increased locomotive problems was also found, which may reflect the loss of appetite suffered by lame cows. This study also concluded that locomotive problems adversely affect the milk production of dairy cows (but not during the 1st lactation), and that high-yielding cows are more prone to problems. The non-significant impact of genetic group on locomotion, irrespective of other factors, is an indication of good herd management.

Table 3.1 Locomotion scoring system used at Crichton Farm

Score	Description
1	Perfect – even tracking, no adduction/abduction
2	Adduction/abduction but even tracking, even non-tracking
3	Uneven, short strides
4	Lame
5	Difficulty turning

Table 3.2 Least square mean estimates of explanatory variables for locomotion score of heifers and cows. Note that, when DIM was included in the analysis of locomotion score, month of inspection was omitted from the model.

	Locomotion score			
Independent variables	Heifer	s.e.	Cow	s.e.
No. of observations	4,628		9,398	
Overall mean	1.90		2.10	
Age at calving (days/100)	L = 0.16^{NS}	0.095	L = 0.077^{NS}	0.078
	Q = -0.12^{NS}	0.070	Q = -0.0038^{NS}	0.0039
Body weight (kg/100)	L = -0.057^{NS}	0.034	L = -0.14***	0.028
	Q = 0.022^{NS}	0.022	Q = -0.027^{NS}	0.016
Condition score	L = -0.051^{NS}	0.047	L = 0.064*	0.032
	Q = 0.17*	0.069	Q = 0.10**	0.036
DIM	L = 0.075*	0.033	L = 0.15***	0.021
	Q = 0.012^{NS}	0.038	Q = 0.029^{NS}	0.028
Mgt group XE v. XM	0.23**	0.069	0.33**	0.072
Genetic group S v. C	0.053^{NS}	0.071	0.043^{NS}	0.071
Lactation 3 v. 2			-0.037^{NS}	0.18
Lactation 4 v. 2			0.15^{NS}	0.30
Lactation 5 v.2			0.14^{NS}	0.44

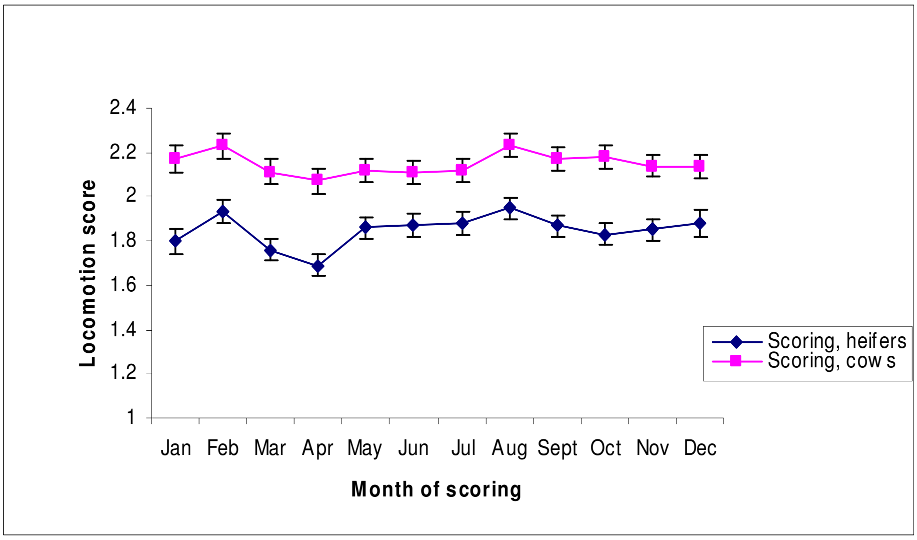
L = linear coefficient; Q = quadratic coefficient; DIM = days in milk; Mgt = management; s.e. = standard error. DIM as included in the model = (actual days in milk-175)/175 and so values lie between ±1.

Table 3.3 Least square mean estimates of explanatory variables for milk yield of heifers and cows. Note that, when days in milk (DIM) were included in the analysis of locomotion score, month of inspection was omitted from the model.

	Daily milk yield			
Independent variables	Heifer	s.e.	Cow	s.e.
No. of observations	32,585		66,066	
Overall mean	26.0		30.2	
Age at calving (days/100)	L = 1.4^{NS}	1.07	L = 1.7*	0.82
	Q = -0.17^{NS}	0.81	Q = -0.072^{NS}	0.042
Body weight (kg/100)	L = 2.9***	0.034	L = 1.8***	0.23
	Q = -0.53**	0.13	Q = -2.2***	0.13
Condition score	L = -0.080^{NS}	0.28	L = -1.7***	0.24
	Q = -0.90*	0.40	Q = -1.2***	0.27
DIM	L = -9.2***	0.30	L = -14***	0.26
	Q = -3.5***	0.23	Q = -2.4***	0.22
	C = 5.2***	0.41	C = 6.2***	0.39
Mgt group XE v. XM	4.1***	0.84	6.0***	1.56
Genetic group S v. 1	3.6***	0.82	6.5***	0.38
Locomotion 3 v. 1	0.0083^{NS}	0.14	0.35*	0.16
Locomotion 3 v. 1	0.14^{NS}	0.25	-0.074^{NS}	0.23
Locomotion 4 v. 1	0.20^{NS}	0.36	-0.78**	0.28
Locomotion 5 v. 2			-5.5^{NS}	3.00
Lactation 3 v. 2			-2.7^{NS}	1.80
Lactation 4 v. 2			-3.3^{NS}	3.00
Lactation 5 v. 2			-5.5^{NS}	4.60

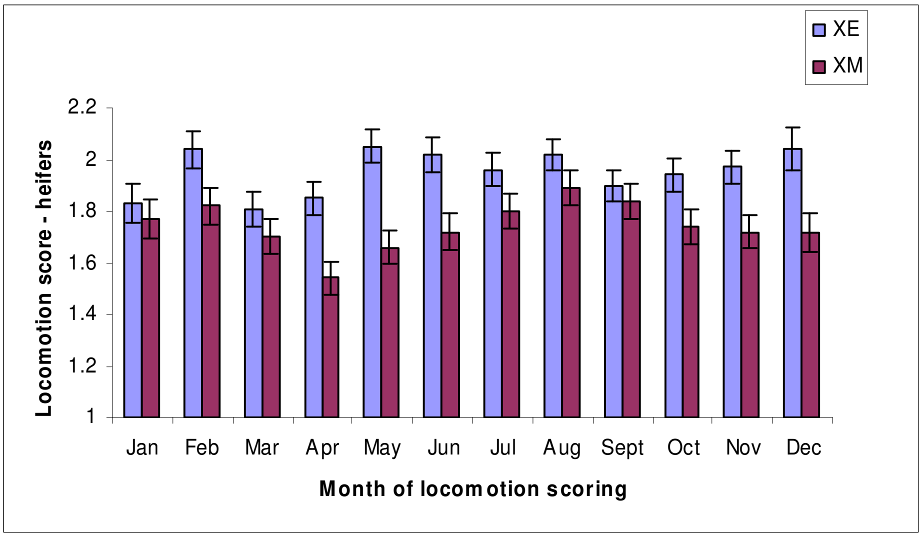
L = linear coefficient; Q = quadratic coefficient; C = cubic coefficient; Mgt = management; s.e. = standard error. DIM as included in the model = (actual days in milk-175)/175 and so values lie between ±1.

Figure 3.1 Predicted incidence of lameness by month of scoring. Month of locomotion scoring for heifers and month of locomotion scoring for cows are shown.



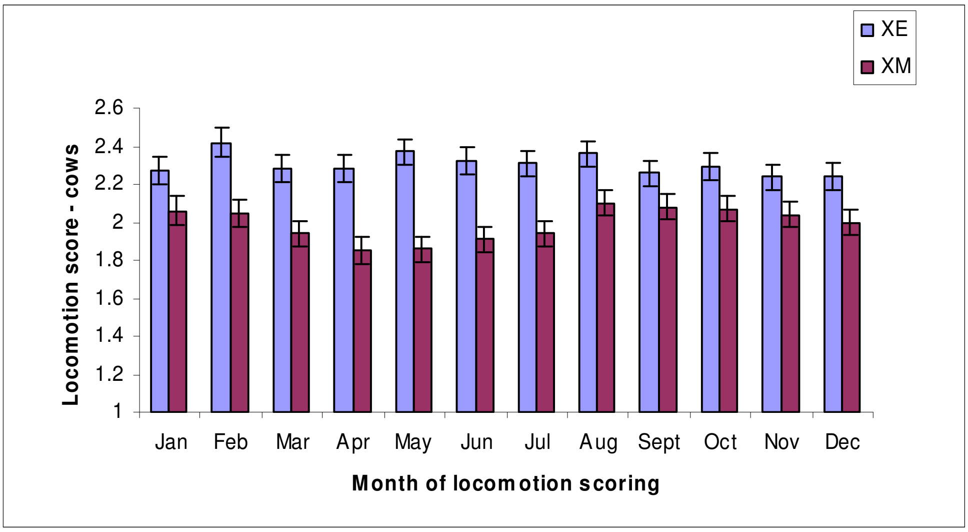
For X-axis, Jan = January, Feb = February, Mar = March, Apr = April, Jun = June, Jul = July, Aug = August, Sept = September, Oct = October, Nov = November and Dec = December.

Figure 3.2(a) Predicted influence of management group on locomotion of heifers.



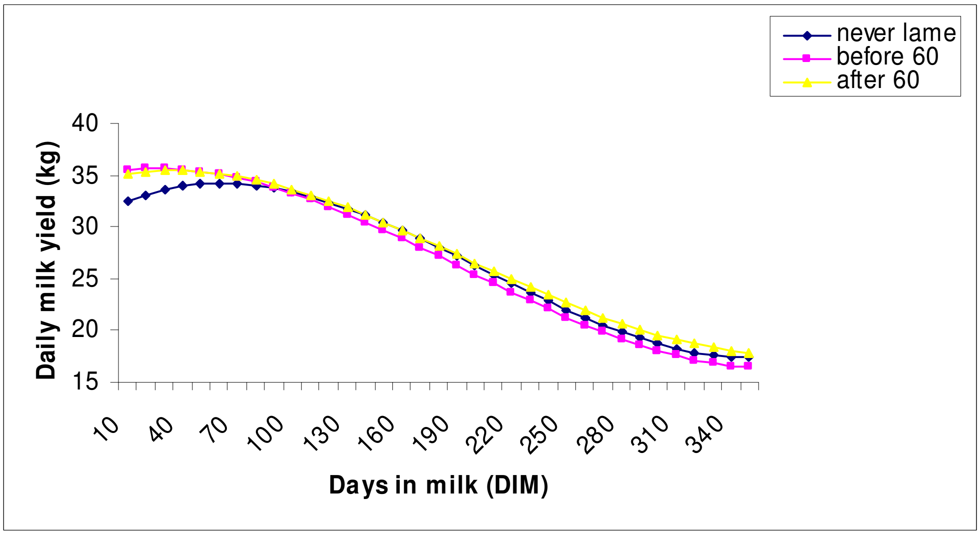
XM = at grass in summer/fed a low concentrate diet and XE = housed all year/fed a high concentrate diet. Labelling for X-axis is the same as in Figure 3.1.

Figure 3.2(b) Predicted influence of management group on locomotion of cows.



XM = at grass in summer/fed a low concentrate diet and XE = housed all year/fed a high concentrate diet. Labelling for X-axis is the same as in Figure 3.1.

Figure 3.3 Milk production curves for lame versus non-lame cows.



CHAPTER 4

GENETIC ANALYSIS OF LOCOMOTION AND ASSOCIATED CONFORMATION TRAITS OF HOLSTEIN-FRIESIAN DAIRY COWS MANAGED IN DIFFERENT HOUSING SYSTEMS

4.1 Summary

The objectives of this study were to determine the influence of housing on lameness-related linear and composite traits, and to estimate heritabilities of the traits and correlations among them. Data comprised 156,770 national type evaluation records of pedigreed first-lactation Holstein-Friesian cows that calved from 2000 through 2006 and were classified in different housing systems—cubicles, straw yards, slatted or loafing yards, and on pasture. Locomotion score (LOCO), rear legs, side view (RLS), foot angle (FA), bone quality (BONEQ), legs and feet (L&F), and mammary composite (MAMM) were the traits measured. Data were analysed by REML, using an animal model. In general, cows in grazing systems had better locomotion, straighter RLS, steeper FA, flat and more refined bones, better L&F, and better mammary systems compared with cows housed in other systems. Estimates of heritability ranged from 0.11 for LOCO to 0.31 for MAMM. Bone quality had the highest heritability (0.23) of the traits associated with L&F. Genetic associations between BONEQ and LOCO, L&F, and MAMM were moderate to high (0.30 to 0.50), but estimates between BONEQ and RLS and FA were not significantly different from zero. Locomotion score had a very high genetic (0.98) and phenotypic (0.78) correlation with L&F, indicating that both traits are genetically the same. On the basis of the genetic parameters, including BONEQ in a selection index as a predictor of longevity is promising, but further information on its association with longevity is required.

4.2 Introduction

The main emphasis in dairy cattle improvement is to increase profit by breeding high-yielding healthy cows with sound feet and legs. Locomotive traits have been shown to affect longevity and hence profit (Booth *et al.*, 2004; Esslemont, 1990), and most countries include traits associated with feet and legs in their national selection index (Miglior *et al.*, 2005).

Environmental variability in locomotion traits is associated with differences in management and housing systems (Broom, 1990; Esslemont, 1990). Bergsten (2004) reported that floors in intensive farming systems are mostly made of non-yielding concrete, which gets slippery over time, and manure contamination is widespread; the result of this is increased locomotion disorders. Studies have reported an increased prevalence of hoof lesions with solid concrete floors compared with straw yards (Webster, 2002; Somers *et al.*, 2003). Similar results were observed with solid concrete floors versus slatted concrete floors (Frankena *et al.*, 1992) and solid concrete floors versus rubber slats (Hultgren and Bergsten, 2001). In the United Kingdom, information on housing type and flooring quality is routinely collected at the same time the cows are type-classified, providing the opportunity to estimate associations among type traits and housing by using national data.

On the basis of genetic correlations of clinical lameness with type traits, Boettcher *et al.* (1998) suggested that foot angle, rear leg set, and rump width could provide an indication of susceptibility to locomotion problems. Old age, deep udders, sickled legs, and long hoof diagonals have also been associated with locomotion problems in cows (Boelling and Pollot, 1998b).

Several studies have estimated genetic parameters for locomotion traits for inclusion into lifetime economic merit indices (Weigel *et al.*, 1998; Stott *et al.*, 2005). In the United Kingdom, recording of type traits dates back more than 20 years, and a trait describing the locomotion of animals was introduced 10 years ago. Although estimates of heritabilities and genetic correlations among linear and miscellaneous type traits (Brotherstone *et al.*, 1990), as well as among type and production traits (Brotherstone, 1994), have been reported for UK Holstein-Friesian cows, as yet no genetic associations of locomotion with other type traits have been published.

Bone quality (**BONEQ**) is a new trait in the UK type classification scheme and is not routinely classified in many other countries. As a result, little information is available in the literature on the genetic and phenotypic relationships of BONEQ with other type traits, in particular type traits associated with longevity. Bone quality is measured on a linear scale from thick and coarse bone to flat and refined bone. Gordon and Shannon (2002) reported that BONEQ is an indication of fitness and good circulation through the legs and has a strong positive genetic correlation with dairy character and milk production. Flat- and fine-boned cows will walk better as a result of decreased bone mass and reduced surface area of contact, particularly at the hock joints, which could minimize leg problems. Dekkers *et al.* (1994) reported that BONEQ had a moderate genetic association with longevity.

4.3 Objectives

The aims of this research were 1) to determine the influence of housing system on linear and composite type traits related to lameness in Holstein-Friesian dairy cows, 2) to estimate the heritability of locomotion and its genetic correlation with other traits related to legs and feet, and 3) to investigate whether BONEQ is a useful type trait to collect, particularly with respect to its genetic association with locomotive problems.

4.4 Materials and Methods

4.4.1. Data

Data were those used for UK national type evaluations. The data set consisted of 156,770 type classification records of pedigreed first-lactation Holstein-Friesians calving from 2000 through 2006. The reason for not including records prior to 2000 is that collection of housing information began that year.

The type traits involved in the analysis were the linear traits locomotion score (**LOCO**), rear legs, side view (**RLS**), and foot angle (**FA**), the overall subjective type traits legs and feet (**L&F**) and mammary composite (**MAMM**), and BONEQ. Mammary composite, which is highly correlated with linear traits describing udder conformation, was included because many of the udder traits have been shown to be associated with clinical lameness (Boettcher *et al.*, 1998). The linear traits are scored from 1 to 9, where 1 and 9 represent biological extremes, and the composite traits are scored from 65 to 95, which represents a continuum on a scale from “poor” to “excellent.” A brief description of the traits is given in Table 4.1, whereas the locomotion scoring system used for the national herds is defined in Table 4.2.

Cows were between 19 and 50 month of age at inspection. Herds were visited a maximum of once every 10 months to avoid classifying animals more than once per lactation.

4.4.2. Housing Information

Three pieces of housing information were routinely collected by the field officers: 1) Housing type—cows were recorded as being housed in 1 of 4 different categories of housing: cubicles, straw yards, on pasture, and others (slatted and loafing yards). 2) Time spent in housing—the amount of time the animal had spent in a particular type of housing was recorded. This allowed me to differentiate between (for example) an animal that had spent a month on pasture and one that had been on pasture for 4 months. 3) Floor condition at classification—the condition of the farm flooring on which the type classification took place was graded from 1 to 5, depending on how slippery and even the flooring was. A poor flooring condition (floor 1) was characterized by slippery, dirty surfaces and holes in the concrete, whereas the ideal condition (floor 5) denoted non-slippery, clean, and level surfaces. Although this assessment was based on the floor where the cows were classified, I would expect this floor condition to be related to the floor condition on all parts of the farm and also to be related to the overall management of the dairy. Evaluation of the flooring by scorers was subjective. The numbers of cows scored on floor conditions 1, 2, 3, 4, and 5 were 25,284, 4,894, 15,408, 32,491, and 78,693, respectively.

4.4.3. Statistical Analysis

Analysis was by univariate REML, using an animal model. The pedigree file comprised 309,881 animals. Because of the small number of animals spending 6 or more months in a particular type of housing, the amount of time in a particular housing type was reclassified as 1, 2, 3, 4, or 5months and then 6 or more. Similarly, few animals were recorded in slatted or loafing yards, so no account of the amount of time in this housing type was made. The total numbers of cows classified in cubicles, straw yards, on pasture, and in slatted or loafing yards were 97,511, 8,535, 49,655, and 1,069, respectively. A preliminary analysis indicated that housing type, month in housing, and their interaction removed a significant amount of variation in the type traits, so in the final model, months in housing was nested within housing type. I will refer to this combined effect as the housing situation. Herd-year-visit was included as a random effect because it was confounded with floor condition.

The mixed-model equation used to describe the data is

$$Y_i = \mu + hyv + \sum_{n-1}^{2} \chi_n age^n + \sum_{n-1}^{2} \beta_n stage^n + \delta.phols + moc + hfloor + hcode.hmns + anim_i + e_i$$

where

Y_i is the type trait measurement on animal i, μ is the overall mean, *hyv* is the herd-year-visit group where animal i was measured, χ_1 and χ_2 are the linear and quadratic regression coefficients of traits on the age of animal i at inspection, β_1 and β_2 are the linear and quadratic regression coefficients of traits on stage of lactation (stage) of animal *i* at inspection, δ is the linear regression of traits on the proportion of Holstein genes (*phols*) in the animal, *moc* is the month of calving of the animal, *hfloor* is the floor condition when animal *i* was inspected, *hcode.hmns* is the housing situation (type of housing and time spent in each type of housing), $anim_i$ is the random genetic effect of the animal, and e_i is the residual random error.

To account for differences in the range of scoring used by the field officers, each trait was first scaled by the ratio of the standard deviation of the classifier to the mean standard deviation of all classifiers (Brotherstone, 1994). Heritability for each trait was calculated from cow and residual variance components. Estimation of genetic correlations between BONEQ, LOCO, and the other traits was by multiple-trait REML in an animal model. For computing convenience, the analysis involved a subset of the original data comprising 37,065 type classification records of cows type-classified from the beginning of 2005. Even with the reduced data set, a multivariate analysis with all 6 traits was not possible because of computing difficulties, so 2-trait analyses (i.e., 9 bivariate analyses in total) were performed with BONEQ and each of the other 5 traits in turn, as well as with LOCO and each of the 4 remaining traits. All analyses were carried out by using ASREML software (Gilmour *et al*., 2000).

4.5 Results

4.5.1 Housing Effect

In general, the covariates (mean proportion of Holstein genes, age of cow at inspection, and stage of lactation at inspection) and month of calving were significant ($P < 0.05$). Results from the analysis of variance (ANOVA) showed that the effect of housing situation was significant ($P < 0.05$) for all traits. Predicted effects of the housing situation on the type traits are given in Table 4.3. Results presented are for 5months in a particular housing type and are relative to 5 months on pasture. Results are similar irrespective of the number of months in a particular housing type. Compared with cows on pasture, cows housed in the 3 housing systems had significantly poorer scores for overall L&F ($P < 0.05$). Cubicle housing was also associated ($P < 0.05$) with poorer locomotion and lower BONEQ scores. Locomotion score, RLS, FA, and MAMM scores of cows in straw yards were significantly lower ($P < 0.05$) compared with the scores of cows on pasture, indicating that cows are also more susceptible to locomotive disorders in straw yards than on grass. The BONEQ of cows in straw-bedded yards did not differ significantly from the BONEQ of cows on pasture. Cows kept in loafing yards, on slatted floors, or both had straighter RLS and poorer L&F compared with cows on pasture. Generally, the results indicate that cows on pasture had fewer locomotive disorders than cows in other types of housing.

The quality of flooring removed a significant ($P < 0.05$) amount of variation for all the traits measured. Table 4.4 gives the influence of flooring condition on the traits. Predicted values are relative to poor flooring condition. Cows classified on floor conditions 4 and 5 had significantly ($P < 0.05$) better scores for L&F than those classified on floor conditions 1 to 3. Cows scored on floor condition 4 had significantly ($P < 0.05$) better LOCO, straighter RLS, steeper FA, and more flat and refined BONEQ compared with cows scored on the poorest floor condition. A reduced score for BONEQ was linked to floor condition 5, and MAMM was highest for cows type-classified on the poorest floor conditions. This association is not intuitive and cannot be explained.

4.5.2 Genetic Parameters

Heritability estimates (**h^2**) for all type traits, genetic (**r_g**) and phenotypic (**r_p**) correlations among BONEQ, LOCO, and the other traits, and standard errors are shown in Table 4.5. The heritabilities ranged from 0.11 for LOCO to 0.31 for MAMM. Heritability of BONEQ (0.23) was higher than the values for the other traits associated with L&F.

Phenotypic correlations with BONEQ were positive and, in general, were smaller in magnitude than the genetic correlations. Genetic correlations of BONEQ with LOCO, L&F, and MAMM were moderate to high (0.30 to 0.50), an indication that finer BONEQ is associated with better locomotion and a superior mammary system. Genetic associations of BONEQ with FA and RLS were not significantly different from zero.

Phenotypic correlations of LOCO with the type traits were generally positive and lower in magnitude than the corresponding genetic relationships. Locomotion score had moderate genetic correlations with FA and MAMM, suggesting that steeper FA and well-fitted mammary systems are associated with better locomotion. Locomotion score and L&F were highly genetically (0.98) and phenotypically (0.78) correlated. A similar result has been found by other researchers (S. Brotherstone, unpublished data; van der Waaij *et al.*, 2005). The genetic association between LOCO and RLS was negative, which indicates that sickled hocks are associated with poorer locomotion.

4.6 Discussion

4.6.1 Effect of Housing on Locomotive Traits

Reported associations among linear and composite type traits and different housing systems are scarce in the literature. However, significant differences in mean phenotypic scores of type traits (heel depth; FA; RLS; rear leg, rear view; BONEQ; and overall L&F) between free-stall and tie-stall housing systems have been reported (Fatehi *et al.*, 2003). My results show that, in general, cows on pasture had higher linear scores and better composite scores compared with cows in other housing systems. Studies have reported reduced claw disorders in cows on pasture compared with cows in other housing systems (Frankena *et al.*, 1991; Somers *et al.*, 2003). In small scale Kenyan herds, Gitau *et al.* (1996) found that cows with access to grazing had a reduced risk of lameness compared with those with no access to grazing. The better L&F and fewer locomotive problems found in cows on grass could be attributed to the fact that grass is a softer environment for lying and rising. This continues to underline the importance of softer housing environments for reducing the incidence of claw and locomotion problems. Fregonesi (1999) showed that dairy cows preferred standing on soft surfaces (straw yards) rather than on concrete floors (cubicle systems). Results obtained from the analysis of flooring condition (Table 4.4) indicate that well-managed, nonslippery, and level floor surfaces minimize locomotion disorders.

4.6.2 Genetic Analysis

4.6.2.1 Heritability

The type traits associated with L&F had genetic components of variation significantly greater than zero and were low to moderately heritable. In general, the heritability of LOCO (h^2 = 0.11) is in agreement with previous estimates (h^2 = 0.10) for Holstein-Friesian dairy cows (Stott *et al*., 2005; van der Waaij *et al*., 2005). Heritabilities for RLS, FA, and L&F were slightly lower than earlier reports. With a sire model, Brotherstone (1994) obtained heritability estimates of 0.19, 0.27, and 0.32, whereas van der Waaij *et al*. (2005) reported estimates of 0.22, 0.18, and 0.24, respectively, for the traits. The heritabilities of BONEQ and L&F in my study are consistent with the results of Fatehi *et al*. (2003), who reported a range of 0.24 to 0.29 for BONEQ and 0.15 to 0.17 for L&F in free-stall vs. tie-stall environments. Van Dorp *et al*. (2004), in a study of the genetics of locomotion, estimated a heritability of 0.30 for BONEQ in Canadian Holsteins. My heritability estimate for BONEQ (0.23) suggests that direct selection for flat and refined bone in dairy cows could be moderately successful.

4.6.2.2 Correlations of BONEQ with Linear and Composite Traits

Results from the multivariate analysis indicate moderate genetic associations between BONEQ and both LOCO and L&F. This is not surprising because these traits describe a general assessment of the L&F. The results indicate that selection for good mobility, good L&F, or both would lead to improvement in BONEQ and vice versa. According to Rogers (1996), selecting for improved BONEQ may be useful for improving leg traits. Van Dorp *et al*. (2004) estimated a moderate genetic correlation of 0.25 between BONEQ and locomotion and reported that BONEQ might be affected by poorly designed stalls. In an analysis of QTL affecting lameness and leg conformation traits, Buitenhuis *et al*.

(2007) reported a moderate genetic correlation (−0.49) between lameness and BONEQ in Danish Holstein dairy cattle and concluded that lameness could be reduced by increasing the frequency of the superior QTL genotype for BONEQ. My result is in agreement with the result of this genomic study showing that locomotion could be improved by selecting for improved BONEQ.

The estimated genetic correlation of 0.30 between BONEQ and MAMM suggests that cows with flat and refined bones are more likely to have well-attached and rounded udders. Considering the moderate heritability estimate of BONEQ and its high genetic association with LOCO, breeding for flatter, more refined BONEQ seems a promising method of reducing locomotion problems and thereby increasing dairy cow longevity. In the United Kingdom, an index of 3 type traits—foreudder attachment, L&F composite, and MAMM—is used together with somatic cell count (SCC) in a phenotypic prediction of longevity, and is included in the national genetic evaluations for longevity as a correlated trait (Brotherstone *et al.*, 1998). Including BONEQ in this index may improve its accuracy. However, an investigation to estimate the association of BONEQ with longevity is needed.

No significant genetic relationship was found between BONEQ and both RLS and FA. This is surprising because FA and RLS had moderate genetic correlations with LOCO, which had a high genetic association with BONEQ. A possible explanation is the existence of a nonlinear relationship between these traits. To investigate this, residuals for FA and RLS were regressed on residuals for BONEQ. The results (not shown) indicated a significant linear but nonsignificant quadratic association between BONEQ and the 2 traits.

The phenotypic correlations between BONEQ and LOCO, FA, L&F, and MAMM imply that, phenotypically, cows with fewer locomotive problems, a steeper FA, a high L&F score, and a superior mammary system had flatter, more refined bones.

4.6.2.3 Correlations between LOCO and the Other Traits

The moderate genetic associations of LOCO with FA and MAMM imply that cows with low FA and sagging or pendulous udders are most likely to suffer lameness. Boettcher *et al*. (1998) obtained strong but negative genetic correlations between FA and clinical lameness from linear (−0.76) and threshold (−0.64) models, and concluded that a flatter

FA is genetically associated with increased clinical lameness. The negative genetic correlation between locomotion and RLS suggests that cows with a straight leg set will have improved walking ability.

The tight genetic relationship between LOCO and L&F strongly suggests that the same genes control both traits. Thus, sound locomotion is closely associated with good L&F. Paget *et al*. (2003) reported a high genetic correlation of 0.91 between locomotion and the L&F composite for UK Guernseys. In the Netherlands, van der Waaij *et al*. (2005) reported a genetic and phenotypic correlation of 0.98 and 0.85, respectively, between LOCO and L&F for Dutch Holstein-Friesian dairy cows. Classifiers consider mobility while evaluating L&F, so a high genetic association between the 2 traits is expected.

The negative phenotypic correlation between LOCO and RLS indicates that, phenotypically, cows with good locomotion have straighter legs. The associations between LOCO and FA and MAMM suggest that cows with steeper FA and better mammary systems are phenotypically predisposed to better locomotion. Phenotypically, the strong association of LOCO with L&F is evidence that cows with good L&F scores had better mobility.

4.7 Conclusions

Cows on pasture had favorable type trait scores compared with cows in other housing systems. Nonslippery, level floor surfaces were associated with fewer locomotion problems and better L&F. Locomotion had a high genetic correlation with L&F and a moderate genetic association with FA and MAMM, indicating that cows with higher scores for L&F and MAMM and with steeper FA had genetically better locomotion. The moderate and positive genetic associations between BONEQ and LOCO and L&F suggest that selection for flat and refined bones will result in improved locomotion.

Bone quality is moderately heritable.

Table 4.1 Description of type traits considered in the analyses

Type trait	Abbreviation	Description	Score 1	Score 9	Mean	SD
Locomotion	LOCO	Walking potential	Lame	Normal	5.37	1.42
Rear legs, side view	RLS	Angle of the hock when viewed from side	Straight	Sickled	5.18	1.35
Foot angle	FA	Angle at the front of rear hoof from base to hairline	Low	Steep	5.15	1.38
Bone quality	BONEQ	Degree of flatness or fineness of bone	Thick and coarse	Flat and refined	6.18	1.31
			Composite score 65	Composite score 95		
Leg and feet composite	L&F	Combination of all traits and mobility	Poor	Excellent	79.74	5.06
Mammary composite	MAMM	Combination of all traits relating to teat and udder positioning	Poor	Excellent	79.98	5.17

Table 4.2 Descriptions of locomotion scores

Locomotion score	Description
1	Lame
2	Severe abduction or adduction present, uneven gait, short strides
3	Abduction or adduction present, uneven gait
4	Slight abduction or adduction present, even gait short strides
5	No abduction or adduction present, even gait, short strides
6	Slight abduction or adduction present, even gait, medium strides
7	Slight abduction or adduction present, even gait, long strides
8	No abduction or adduction present, even gait, medium strides
9	No abduction or adduction present, even gait, long strides

Table 4.3 Predicted effects ± SE of the housing system on type traits relative to cows housed on pasture

	Trait[1]					
Housing situation	LOCO	RLS	FA	BONEQ	L&F	MAMM
Cubicles	-0.12* ± 0.03	0.05 ± 0.03	0.12* ± 0.03	-0.21*± 0.03	-0.53* ± 0.11	0.19 ± 0.10
Straw yard	-0.22* ± 0.07	0.59* ± 0.10	-0.42* ± 0.06	-0.03 ± 0.07	-1.36* ± 0.23	-0.86* ± 0.21
Slatted floor or loafing yard	-0.02 ± 0.09	-0.27* ± 0.08	-0.01 ± 0.08	0.08 ± 0.09	-0.85* ± 0.30	-0.19 ± 0.28

[1]LOCO = locomotion score; RLS = rear leg, side view; FA = foot angle; BONEQ = bone quality; L&F = leg and feet composite; MAMM = mammary composite.
*P < 0.05.

Table 4.4 Predicted effects ± SE of flooring condition on the locomotion type traits relative to a flooring condition score 1[1]

	Trait[2]					
Flooring Condition	LOCO	RLS	FA	BONEQ	L&F	MAMM
2 vs. 1	-0.05 ± 0.04	-0.11* ± 0.04	-0.05 ± 0.04	-0.31* ± 0.05	-0.48* ± 0.15	-0.77* ± 0.14
3 vs. 1	0.04 ± 0.03	-0.10* ± 0.03	0.06* ± 0.03	-0.26* ± 0.03	-0.16 ± 0.11	-0.56* ± 0.10
4 vs. 1	0.23* ± 0.03	-0.13* ± 0.04	0.11* ± 0.02	0.14* ± 0.03	0.57* ± 0.08	-0.52* ± 0.08
5 vs. 1	0.09* ± 0.02	0.002 ± 0.02	0.05* ± 0.02	-0.08* ± 0.03	0.58* ± 0.08	-0.47* ± 0.08

[1]Flooring condition scored as 1 = slippery, dirty surfaces with holes in concrete; 2 = even concrete, but slippery underfoot; 3 = uneven or sloping concrete; 4 = level concrete; 5 = perfect non-slippery, clean and level surfaces.
[2]LOCO = locomotion score; RLS = rear leg, side view; FA = foot angle; BONEQ = bone quality; L&F = leg and feet composite; MAMM = mammary composite.
*P < 0.05.

Table 4.5 Heritabilities (h^2) of type traits and genetic (r_g) and phenotypic (r_p) correlations of bone quality with other conformation traits and locomotion and of locomotion score with conformation traits together with SE

Type traits[1]	h^2	SE (h^2)	r_g	SE (r_g)	r_p	SE (r_p)
BONEQ	0.23	0.010				
LOCO	0.11	0.007	0.50	0.076	0.26	0.006
RLS	0.15	0.008	0.08	0.084	0.00	0.006
FA	0.11	0.007	-0.10	0.086	0.03	0.006
L&F	0.18	0.009	0.50	0.067	0.33	0.006
MAMM	0.31	0.011	0.30	0.068	0.22	0.007
LOCO	-	-				
RLS	-	-	-0.26	0.099	-0.16	0.006
FA	-	-	0.30	0.099	0.20	0.005
L&F	-	-	0.98	0.008	0.78	0.002
MAMM	-	-	0.48	0.076	0.23	0.006

[1]LOCO = locomotion score; RLS = rear legs, side view; FA = foot angle; BONEQ = bone quality; L&F = leg and feet composite; MAMM = mammary composite

CHAPTER 5

Genetic Parameters for Digital Dermatitis and Correlations with Locomotion, Production, Fertility Traits, and Longevity in Holstein-Friesian Dairy Cows

5.1 Summary

Heritability of digital dermatitis (DD) and correlations between DD and type traits related to legs and feet were estimated from a linear animal model. Data comprised 93,391 national type evaluation records of pedigreed first-lactation Holstein-Friesian cows that calved from 2002 through 2006. At the time of classification, cows were housed in different housing systems (i.e., cubicles, straw yards, slatted or loafing yards) and on pasture. The type traits evaluated were locomotion score (LOCO), rear legs, side view (RLS), foot angle (FA), bone quality and leg and feet composite (L&F). In addition, cows were examined for DD lesions at classification. The relationships among these type traits, lifespan (LS), production (milk and fat), fertility (calving interval and 56-d nonreturn) and DD were examined by estimating the approximate genetic correlations from sire estimated breeding values. The study also evaluated the association between DD and the housing systems as well as the general conditions of the farm flooring where classification took place. In general, cows on pasture were less susceptible to DD than cows in other housing systems, whereas the association between DD and the flooring conditions was counter-intuitive. Heritability estimate for DD was 0.011 on the 0/1 scale, which is equivalent to 0.029 on the assumed underlying normally distributed scale. Bone quality, LOCO, and L&F had moderate to high negative genetic correlations with DD, indicating that flatter, more refined bones, higher LOCO, and better L&F were associated with less incidence of DD. The genetic correlations between DD, RLS, and FA were not significantly different from zero. Digital dermatitis had moderate but negative genetic correlations with LS and milk and fat, suggesting that breeding for resistance to DD will result in an increase in both longevity and production. Cows affected with DD had a slightly shorter calving interval than healthy cows, an association found to be mediated through the reduced milk yield of these cows. Generally, the type traits included in this study had low genetic correlations with production and fertility traits whereas the associations between these traits and LS ranged from moderate to high. This indicates that good locomotion, straighter RLS, steeper FA, better L&F, and flatter, more refined bones are associated with increased longevity.

5.2 Introduction

Digital dermatitis (**DD**) is an infectious skin disease of cattle that affects the heels and the skin between the digits. It is considered an important cause of lameness in dairy herds due to the associated pain, discomfort, and impaired performance (Read and Walker, 1998). Clarkson *et al.* (1996) surveyed 37 dairy farms in England and Wales and observed that DD constituted 8% of all the hoof lesions contributing to lameness.

Digital dermatitis has been associated with decreased milk yield, reduced reproductive performance, increased involuntary culling rate, and reduced general well-being of the animals (Nutter and Moffit, 1990; Argaez-Rodriguez *et al.*, 1997; Garbarino *et al.*, 2004). Wells *et al.* (1999) reported that 9.7% of DD resulted in lameness in affected cows. Hernandez *et al.* (2001) reported that calving to conception interval was significantly longer in lame cows with multiple lesions including DD, compared with healthy cows. Earlier, Argaez-Rodriguez *et al.* (1997) reported that cows affected by DD in a Mexican herd had a 20-d increase in calving to conception interval, resulting in reduced fertility and consequently a shorter lifespan. The same study also reported a decrease in the milk production of cows affected with DD compared with healthy cows, although the difference was not significant. Corrie *et al.* (2000) noted that papillomatous digital dermatitis was common among culled adult cattle with the incidence greater among dairy cattle compared with their beef counterparts.

Estimates of genetic parameters between claw diseases including DD and locomotion traits were reported by van der Waaij *et al.* (2005). With threshold and linear models, they reported a heritability of 0.10 from both models for DD in Dutch Holstein-Friesian dairy cows. They also reported genetic correlations of 0.16 ± 0.13, −0.22 ± 0.13, −0.67 ± 0.19, and −0.34 ± 0.12 between DD and rear legs, side view (**RLS**), foot angle (**FA**), locomotion score (**LOCO**), and leg and feet composite (**L&F**), respectively. Approximate genetic correlations reported by Koenig *et al.* (2005) between DD and linear type traits ranged from 0.03 (hocks) to −0.61 (FA).

Reports of genetic parameters of DD and genetic associations with locomotion, production, fertility, and longevity traits are few in the literature, yet these estimates are required to enable DD to be included in a genetic selection index. The genetic association of DD with longevity has not been reported so far in the literature.

Studies on environmental and management risk factors have associated the incidence of DD with herd size, stage of lactation, parity, damp floors, housing systems, and so on (Frankena *et al*., 1991; Rodriguez-Lainz *et al*., 1996; Somers *et al*., 2005). Cows housed in cubicles and those with restricted access to pasture were observed to be at greater risk of DD compared with cows that had full access to pasture during summer (Frankena *et al*., 1991; Somers *et al*., 2005). Moist and unhygienic floor conditions as well as solid or grooved concrete floors have also been associated with a greater incidence of DD (Rodriguez-Lainz *et al*., 1996; Wells *et al*., 1999; Hultgren and Bergsten, 2001).

As part of the UK type classification scheme, field officers now routinely collect information on housing systems and flooring conditions (Chapter 4). In addition, the field officers record whether cows exhibit signs of DD during type classification. It is, therefore, now possible in the UK to investigate associations between DD and housing conditions and estimate genetic parameters for DD and associated traits using national data.

5.3 Objectives

The objectives of this study were 1) to determine the influence of housing on the occurrence of DD in Holstein-Friesian dairy cows; 2) to estimate the heritability of DD and its genetic correlation with locomotion and other leg and feet traits; and 3) to estimate approximate genetic correlations among locomotion traits, lifespan (**LS**), production and fertility traits, and DD from sire EBV.

5.4 Materials and Methods

5.4.1 Data

The data used for this analysis comprised 93,391 national type evaluation records of pedigreed first-lactation Holstein-Friesian cows inspected from 2002 through 2006. Data were taken from 2002 because the recording of DD commenced in that year. Digital dermatitis was scored by the field officers on the presence or absence of lesions in the interdigital spaces of the feet. Herd visits were undertaken once every 10 months to avoid type classifying cows more than once per lactation.

Five type traits related to legs and feet were evaluated. The traits are LOCO, RLS, FA, and bone quality (**BONEQ**) measured on a scale of 1 to 9, which represents extreme biological values, and L&F, which was measured on a subjective scale of "poor" (65) to "excellent" (95). Table 5.1 gives a description of the traits scored with their means and standard deviations. See Table 4.2 for the locomotion scoring system used for UK national herds. Age of cows at inspection was between 19 and 50 months.

5.4.2 Housing Information

Field officers subjectively assessed cow housing based on 3 criteria: 1) type of houses where cows were kept; 2) the length of time cows had spent in each housing type; and 3) the general condition of the farm flooring where type evaluation took place, which was scored between 1 (poor) and 5 (ideal). Detailed information on housing is described in chapter 4. The number of cows classified in cubicles, straw yards, on pasture, and in slatted or loafing yards was 60,838, 3,885, 27,901, and 767, respectively; whereas total numbers scored on flooring conditions 1, 2, 3, 4, and 5 were 16,411, 2,723, 9,047, 19,930, and 45,280, respectively.

5.4.3 Statistical Analysis

Data were first adjusted for field-officer differences in scores by scaling records such that the standard deviation of each field officer was equal to the mean standard deviation of all field officers (Brotherstone, 1994).

The model equation used to describe the data was

$$Y_i = \mu + hyv + \sum_{n-1}^{2} \beta_n age^n + \sum_{n-1}^{2} \chi_n stage^n + \alpha.phols + moc + hcode.hmns + hfloor + a_i + e_i$$

where Y_i = presence (1) or absence (0) of DD for animal i; μ = overall mean; hyv = random herd-year-visit effect; β_1 and β_2 = linear and quadratic regression coefficients of DD on age of cow at inspection; χ_1 and χ_2 = linear and quadratic regression coefficients of DD on stage of lactation of cow (stage) at inspection; α = linear regression of DD on the proportion of Holstein genes; $phols$ = proportion of Holstein genes; moc = effect of month of calving; $hcode.hmns$ = housing period effect nested in housing type; $hfloor$ = flooring condition at inspection of animal i; a_i = random animal effect; and e_i = random error term.

The length of time cows spent in a particular housing was classified as 1, 2, 3, 4, 5 months and then 6 or more due to small sample sizes recorded from 6 months. The length of time cows spent in slatted or loafing yards was not accounted for because few animals were recorded in these housing types. Housing period was nested within housing type and the combined effect referred to as housing situation. Cow and herd-year-visit were fitted as random effects in the model. Fitting herd-year-visit as a random effect allowed me to estimate the effect of housing systems and flooring conditions as these factors are confounded with herd visit. Herd-year-visit in this model will account for residual differences after the fixed effects have been accounted for. Housing systems and flooring conditions are both indicative of the overall farm management conditions. Age of cow at inspection, stage of lactation at inspection, and mean proportion of Holstein genes (ranging from 91 to 100%) were included as covariates.

Heritability of DD was estimated from a linear model. The heritability obtained from the linear model was then transformed from the 0/1 scale to an assumed underlying continuous normally distributed scale (Robertson and Lerner, 1949). The transformation applied was

$$h_n^2 = h_{0/1}^2[p(1-p)/z^2],$$

where h_n^2 = heritability on the continuous normal scale; $h_{0/1}^2$ = heritability on the binomial scale; z = ordinate of the standardized normal distribution at the threshold point corresponding to p, and p = incidence of DD; that is, the proportion of cows that had DD.

Genetic and phenotypic correlations between DD and type traits were estimated from a multivariate REML analysis using an animal model. The same model was applied to both DD and the linear traits.

A single multivariate analysis with DD and all 5 type traits was not feasible because insufficient computer memory was available. Therefore, a series of 2-trait analysis (i.e., 5 bivariate analyses) was performed with DD and one of the type traits in turn. No structure was imposed on the variance-covariance matrix. Phenotypic correlations between DD and the type traits ($r_{0/1}$) were also transformed to an assumed underlying normally distributed scale (r_n) by applying the method of Ollausson and Ronningen (1975):

$$r_n = r_{0/1}\left[p(1-p)/z^2\right]^{1/2},$$

where p and z are as above. Genetic correlations on the 0/1 and underlying normal scale are expected to be similar, so no transformation is needed (Ollausson and Ronningen, 1975). The ASREML software was used for all analysis (Gilmour *et al.*, 2000).

5.4.4. Estimation of Approximate Genetic Correlations among Locomotion Traits and Production, Fertility Traits, and Lifespan

Sires' EBV were correlated to obtain approximate genetic correlations among type traits (LOCO, RLS, L&F, FA and BONEQ), production traits (milk and fat), fertility traits [calving interval in days (**CI**) and 56 d nonreturn (**NR56**), scored 0 if the cow returns to service within 56 d and 1 otherwise], and lifespan. Wall *et al.* (2003) describe the UK system to predict EBV for fertility and Brotherstone *et al.* (1997) detail the genetic evaluation of lifespan. The phenotypic lifespan trait is the actual lifespan of the cow, or if she is still alive, her predicted lifespan. Sire EBV for type traits were taken from the output of the analysis described above and their corresponding reliabilities were estimated from the standard errors of the sire solutions as follows:

$$RL_i = 1.0 - \left(SE_i^2 / \sigma^2_{a(i)}\right),$$

where RL_i = sire reliability for trait i; SE_i = standard error of sire EBV for trait i; and $\sigma^2_{a(i)}$ = additive genetic variance for trait i.

Sire EBV and reliabilities for milk, fat, CI, NR56, and longevity were taken from the UK national evaluation records of May 2007. Sires with missing EBV for any of the traits of interest were eliminated. Minimum reliability for type traits used in estimating the correlations was 0.30, resulting in a minimum reliability for production traits, CI, NR56, and lifespan of 0.50, 0.34, 0.35, and 0.32, respectively. Correlations were based on 973 sires.

5.4.5 Estimation of Approximate Genetic Correlations between DD and Lifespan, Production, and Fertility Traits

As described above, sire EBV were correlated to obtain approximate genetic correlations between DD and LS, milk, fat, CI, and NR56. Again, sire EBV for DD were taken from sire solutions and their reliabilities calculated from the standard errors of the solutions.

The low heritability of DD resulted in many bulls having EBV of low reliability. Therefore, the minimum reliability requirement for DD was reduced from 0.30 to 0.10 which resulted in a lower limit of 0.28 (LS), 0.41 (production traits), and 0.27 (fertility traits), respectively. Correlations were based on 2,461 sires.

All correlations estimated from EBV were adjusted for their reliabilities by the method of Calo *et al*. (1973):

$$\hat{r}_{g1,2} = \frac{\sqrt{\left\{\sum RL_1\right\} \times \left\{\sum RL_2\right\}}}{\sum \left\{RL_1 \times RL_2\right\}} \times r_{1,2}$$

where RL_1 and RL_2 = reliabilities of traits 1 and 2; $\hat{r}_{g1,2}$ = approximate genetic correlation between traits 1 and 2; and $r_{1,2}$ = correlation between EBV for traits 1 and 2.

The standard errors of correlations were estimated using the formula below:

$$SE = \sqrt{\frac{1 - \hat{r}^2_{g1,2}}{n - 2}},$$

where n = number of sires with records (Sokal and Rohlf, 1995).

To investigate whether genetic associations between type and fertility were mediated through production, approximate genetic correlations between these traits were adjusted for milk yield. Similarly, the correlations between DD and fertility traits were adjusted for milk yield. The partial correlation coefficients were estimated using the following formula (Sokal and Rohlf, 1995):

$$\hat{r}^{\circ}_{1,2\cdot 3} = \frac{\hat{r}_{g1,2} - \hat{r}_{g1,3}\hat{r}_{g2,3}}{\sqrt{\left\{1 - \hat{r}^2_{g1,3}\right\}\left\{1 - \hat{r}^2_{g2,3}\right\}}}$$

where $\hat{r}^{\circ 2}_{1,2\cdot 3}$ = partial correlation coefficient among DD, CI, and NR56 adjusted for milk yield; $\hat{r}_{g1,3}$ and $\hat{r}_{g2,3}$ = approximate genetic correlations of trait 1 (DD) with milk yield and trait 2 (CI and NR56) with milk yield.

The partial correlations were tested for significance with a *t*-statistic as shown below (Sokal and Rohlf, 1995):

$$t = \hat{r}^{\circ}_{1,2\cdot3}\sqrt{\frac{n-2-m}{1-\hat{r}^{\circ 2}_{1,2\cdot3}}}$$

where m = number of variables kept constant, which is 1 in my case—milk yield.

Standard errors for the partial correlations were estimated in the same way as standard errors of ordinary correlations.

5.5 Results

5.5.1 Descriptive Analysis

The data set consisted of 15,000 herd-year-visit effects, and the proportion of heifers recorded as having DD was 12.1%. The mean incidences of cows with DD per housing type, irrespective of housing period were 0.14, 0.11, 0.08, and 0.14 for cubicles, straw yards, pasture, and slatted or loafing yards, respectively. The mean proportion of cows affected by DD in each housing system relative to the amount of time spent (months) in the system is given in Table 5.2. The incidence of DD was greater in both cubicles and slatted or loafing yards compared with the other housing systems and increased with housing time in cubicles and straw yards (Figure 5.1). Cows showed reduced signs of DD as they spent more time on grass and were less susceptible to DD than cows housed in other systems.

In general, age of cow at inspection, stage of lactation at inspection, and month of calving removed a significant amount of variation in DD and the type traits ($P< 0.05$), whereas the proportion of Holstein genes was not significant.

5.5.2 Housing Situation and Flooring Effect

Housing situation and flooring condition removed significant amounts of variation in DD. Predicted effect of housing situation (relative to pasture for all months) and flooring condition (relative to flooring condition 5) on the incidence of DD is given in Table 5.3. Cows housed in cubicles had significantly ($P < 0.05$) increased DD lesions as the housing period increased compared with cows spending similar periods on pasture. This result is consistent with the mean incidence of DD within each housing period (Table 5.2). Cows kept in straw yards showed significantly ($P < 0.05$) greater signs of DD compared with those on pasture when housed for at least 6 months. The results generally show that cows on pasture were less susceptible to DD than cows in other housing systems.

Poor flooring condition (floor 1) was associated with a reduced incidence of DD whereas flooring condition 4 was associated with a greater incidence of DD compared with the ideal flooring condition. There was no significant difference in DD between cows classified on flooring types 2 and 3 and those on 5.

5.5.3 Heritabilities and Correlations between DD and Type Traits

Estimates of heritabilities of DD and genetic correlations between DD and type traits, together with their standard errors, are given in Table 5.4. The genetic variance of DD was significantly greater than zero and the estimate of heritability was 0.011 (±0.003). After transformation to the underlying scale, the heritability of DD increased to 0.029 (±0.007).

Bone quality, LOCO, and L&F had moderate to high genetic correlations with DD. The estimates were −0.21, −0.67, and −0.63, respectively, suggesting that cows with no DD were genetically superior for flat and refined bone quality, sound locomotion, and better legs and feet. The genetic correlations between DD and RLS and FA were low in size and did not differ significantly from zero.

The phenotypic correlations between DD and the type traits were lower than their corresponding genetic estimates and were all significantly ($P < 0.05$) different from zero. Only RLS had a positive phenotypic association with DD. The result suggests that, phenotypically, cows with no signs of DD have higher linear type scores and better legs and feet. When transformed from the 0/1 scale to the underlying continuous scale, the phenotypic correlations also increased (Table 5.4)

5.5.4 Approximate Genetic Correlations among Type Traits, LS, Milk, Fat, CI, and NR56

Table 5.5 gives the approximate genetic correlations of the type traits with LS, production, and fertility, together with standard errors. The correlations between type traits and LS were all significantly different from zero. Lifespan had high approximate genetic correlations with BONEQ (0.50), LOCO (0.66), and L&F (0.69), suggesting that flat and refined bones, good locomotion, and better legs and feet are associated with increased longevity. Foot angle was moderately correlated with LS; evidence that cows with a steeper foot angle had increased longevity. The correlation between RLS and LS

(−0.32) was negative, indicating that sickled rear legs as judged from the side are associated with reduced lifespan.

The approximate genetic correlations of type traits with milk were all low but significantly different (P<0.05) from zero apart from LOCO. Only the correlation between milk and RLS was positive. The correlations show that daughters of sires with steep FA, good L&F, and refined bones had reduced milk yield. Correlations of type traits with fat were also low but moderate for LOCO (0.22). They were significantly different from zero except the estimates for FA and BONEQ. Based on the genetic correlations, cows with good locomotion and better L&F score will give greater fat yield. Rear legs, side view had a negative correlation with fat, which shows that sickled legs are associated with decreased fat yield.

Generally, the approximate genetic correlations of type traits with NR56 were low, except for that between BONEQ and NR56 (0.36) but significantly different from zero. The correlations indicate that straighter RLS, steeper FA, better L&F, and flatter, more refined bone quality are associated with better conception rate. Correlations with CI were less intuitive but these correlations are subject to management influences. The partial correlations between type and fertility traits adjusted for milk yield are presented in Table 5.6. The partial correlation coefficients were all significant except between L&F and NR56, indicating that only the association between L&F and NR56 is mediated through milk yield.

Lifespan showed a moderate genetic association with milk yield (−0.24), being consistent with previous reports that high milk yield is associated with a shorter lifespan. This was not the case for fat yield because the correlation was not significantly different from zero. Also, LS had a moderate genetic association with CI (−0.49) and NR56 (0.39), suggesting that a longer CI is linked to a reduction in LS, whereas successful conception is associated with increased longevity.

Milk and fat yield had moderate genetic associations with CI, and the correlations were similar (0.27) and significantly different from zero implying that longer CI is associated with increased milk and fat production. Milk, fat, and CI were negatively correlated with NR56, suggesting that high milk or fat yield or longer CI is linked with a lower conception rate.

5.5.5 Approximate Genetic Correlations of DD with LS, Milk, Fat, CI, and NR56

Approximate genetic correlations of DD with LS, milk, and fat were negative and moderate suggesting that the presence of DD is associated with reduced longevity and decreased milk and fat yield. Thus, breeding for resistance to DD should improve both production and longevity.

The association between DD and CI (−0.07) was low and negative, indicating that cows affected by DD had slightly shorter CI than cows with no evidence of DD. From the partial correlation between DD and CI (0.015), it was seen that the shorter CI is mediated through the reduced milk yield of affected cows, because the association was not significantly different from zero. In addition, DD and NR56 were moderately correlated (0.48), indicating an association between DD and greater conception rates. The partial correlation coefficient (0.40) between DD and NR56 (Table 5.6) was still significant, suggesting the correlation is not mediated through milk yield.

5.6 Discussion

To allow estimation of housing and flooring, herd-year-visit was fitted as a random effect. Herd-year-visit comprises many components including time of visit, farm size, grass quality, and field officer biases. The assumption of independent herd-year-visit effects is, to some extent, infringed by the presence of field officer biases. This could be dealt with by including field officer as an additional fixed effect in the model; however, for simplicity I chose not to do this, as I believe these biases are of little importance.

In dairy cattle breeding, considerable interests have been shown in breeding for disease resistance in recent years. Lameness is a complex trait resulting from a joint interaction of many factors including diseases such as DD. Some of these causative factors are heritable. Therefore, improving lameness requires an integrated approach of increasing genetic resistance of cows to diseases influencing lameness together with improving the environmental conditions. DD is a heritable trait and increasing cows' resistance to the problem is expected to be an added advantage in the effort towards reducing lameness in herds. Thus, including DD as a measured trait in the breeding goal would be a useful addition towards increasing the overall productive efficiency of the dairy cow.

5.6.1 Association between Housing System, Flooring Condition, and DD

Results of this analysis show that housing dairy cows in cubicle houses predisposes them to DD infection, and DD increases as housing periods increase. High incidence of DD has been reported for cows kept in cubicles (Frankena *et al*., 1991; Somers *et al*., 2005). Faye and Lescourret (1989) also showed that claw health was worse in indoor cubicle housing than during pasturing. Cubicle houses are characterized by abrasive solid concrete, which causes wear and tear of the cow hooves, thus exposing the inner claws to microorganisms causing infectious diseases such as DD and other injuries. Results from the current study also showed that straw yards predispose cows to DD when housed for extended periods. Straw yards are softer environments than cubicles, and with good management such as daily removal of bedding (which prevents wetness and pathogen build-up), cows should be less vulnerable to DD. There was no significant difference in DD between cows in slatted or loafing yards and those on pasture. However, because the amount of time spent by cows in this system was not accounted for in my analysis, I cannot ascertain whether slatted/loafing yards are compatible with pasture in terms of reduced incidence of DD with longer housing periods. Moreover, a small number of animals were recorded in this system compared with the number of animals at pasture.

Cows with full access to pasture have been found to have a reduced incidence of DD (Wells *et al*., 1999; Somers *et al*., 2003, 2005). My findings corroborate these reports. Figure 5.1 clearly indicates that cows become less vulnerable to DD as they spend more time on pasture. The high incidence of DD experienced by cows on pasture in the first month may be a result of the housing type where cows were housed in the previous month. The association between flooring condition and incidence of DD was counter-intuitive. The lower incidence of DD in dirty, slippery floor conditions compared with the other flooring conditions could be due to difficulty in identifying lesions on dirty feet. As a result, many of the DD cases might go undetected by field officers. Wells *et al*. (1999) reported a lower incidence of DD on dirt, pasture, or smooth concrete compared with grooved concrete.

5.6.2 Estimates of Genetic Parameters

5.6.2.1 Heritability

The heritability estimates for DD in this study were lower than previous reports in literature. Using a sire model, van der Waaij *et al*. (2005) reported an estimate of 0.10 (linear and threshold) for DD in Dutch Holstein-Friesians whereas Koenig *et al*. (2005) obtained an estimate of 0.073 from a linear logistic mixed model. The disparity in these heritability estimates could be attributed to the differences in the number of records as well as the models used in data analysis. Many of the herds in my data had a mean of zero for DD i.e. some herds had no incidence of DD. Therefore, the heritability of DD in this study may have been underestimated due to the zero prevalence in some herds which results in these herds not displaying genetic variation for resistance to the disease. Although my estimates of heritability were low, they were significantly different ($P < 0.05$) from zero, implying that DD is heritable, and genetic improvement for resistance to DD is possible through selection.

5.6.2.2 Genetic Correlations

The association between DD and LOCO (–0.67) is similar to the estimate of van der Waaij *et al*. (2005). The genetic relationships between DD and LOCO and L&F were of similar magnitude in my study and this is not surprising, because both traits have been reported to be highly genetically and phenotypically correlated (van der Waaij *et al*., 2005; chapter 4). The correlations among DD and type traits relating to legs and feet suggest better legs and feet if cows are bred for increased resistance to DD. Conversely, selection for improved type traits would lead to increased resistance to DD. Nonsignificant associations among DD, FA, and RLS were noted by van der Waaij *et al*. (2005).

5.6.3 Approximate Genetic Correlations

5.6.3.1 Correlations among Type, LS, Production, and Fertility Traits

The strong association between the type traits and LS could be linked to the fact that improved conformation particularly related to legs and feet will make cows less vulnerable to locomotive disorders. This is consistent with the correlations between DD and type traits (Table 5.4). Dekkers *et al*. (1994) reported moderate genetic association among BONEQ, L&F, set of rear legs on a desirability scale and functional herd life.

The relationships between FA, RLS, L&F, and BONEQ suggest that lower FA, more sickled rear legs, poorer L&F score, and coarser bones are associated with increased milk production. Perez-Cabal *et al*. (2006) also found that sickled rear legs were associated with increased milk yield. However, they detected a positive association between better legs and feet and greater production, whereas I found that poorer legs and feet score was associated with greater milk yield.

In this analysis, I found no significant association between LOCO and milk yield.

In general, the relationships between type and CI are quite surprising but could be due to management effects. Pryce *et al*. (2000) obtained a negative correlation of FA with CI (−0.20), but positive with RLS (0.19). Because fertility remains an economically important trait in the breeding goals of farmers, and selection for productive life is expected to result in improved health and fertility, the associations between type and fertility traits warrant further research.

5.6.3.2 Correlations among LS, Production, and Fertility Traits

The unfavorable approximate genetic correlation between LS and milk yield is an indication that daughters of sires with high EBV for milk yield will have reduced longevity. The correlations among LS, CI and NR56 were favorable (−0.49 and 0.39, respectively). Cows having shorter CI and successful conception will stay longer in the herd. The antagonistic relationship between CI and NR56 (−0.34) means that a longer CI is associated with a reduced pregnancy rate.

The association between milk, fat, and fertility traits suggests that high-yielding cows will have longer CI and impaired conception leading to reduced reproductive fitness. Poor fertility and health along with low production have been identified as reasons for involuntary culling (Esslemont and Kossaibati, 1997). Many studies have reported similar genetic relationships between production and fertility traits. Wall *et al*. (2003) reported antagonistic correlations between milk yield and CI (0.27) and NR56 (−0.45). Brotherstone *et al*. (2002) estimated unfavorable genetic correlations between combined 305-d fat and protein and CI (0.40) and NR56 (−0.29). These findings support the inclusion of fitness related traits with production in national selection indices (Miglior *et al*., 2005).

5.6.3.3 Correlations among DD, LS, and Production

Correlation of the EBV adjusted for their reliabilities among DD, LS, and milk and fat (−0.16, −0.31, −0.43, respectively), suggest that increased incidence of DD is associated with reduced LS and decreased milk and fat production. Contrary to my estimate, Koenig *et al*. (2005) obtained a positive correlation between DD and milk yield in the first stage of lactation (0.24) but the analysis involved a small data set.

As the presence of DD was identified by field officers rather than veterinarians and was scored only once in first lactation, the incidence of the disease as estimated from my data may be biased downwards. However, recording the presence of DD on the national population (around 60,000 heifers per year are type classified in the UK) should give sufficient information to predict sire breeding values for DD of reasonable reliability.

Results from my analyses indicate that breeding for increased resistance to DD is associated with an increase in both longevity and production. Thus, DD should be considered a useful disease trait to be recorded and included in a national selection index for increased productive life.

5.7 Conclusions

Cows at pasture had reduced incidence of DD compared with cows in other housing systems. Also, cows with flatter and more refined bones, higher locomotion score, and better leg and feet composite had reduced incidence of DD. Digital dermatitis showed heritable variation among cows and was moderately associated with lifespan and production. Therefore, I can assume that its inclusion in a selection index will be useful to improve the resistance of cows to the disorder and increase lifespan. However, due to the rather low heritability estimate, performing selection index calculations is necessary in order to ascertain whether or not DD will make any significant contribution to the overall production efficiency. The genetic correlations between type traits related to legs and feet and lifespan ranged from moderate to high, whereas, in general, these type traits had low associations with production and fertility.

Table 5.1 Description of traits

Type traits and DD	Abbreviation	Score: 1	Score: 9	Mean	SD
Locomotion score	LOCO	Lame	Normal	5.43	1.46
Rear leg, side view	RLS	Straight	Sickled	5.07	1.37
Foot angle	FA	Low	Steep	5.17	1.40
Bone quality	BONEQ	Thick and coarse	Flat and refined	6.29	1.31
		Composite score			
		65	95		
Leg and feet	L&F	Poor	Excellent	79.96	4.92
		Disease score			
		0	1		
Digital dermatitis	DD	Absent	Present	0.12	0.33

Table 5.2 Mean proportion of cows affected by digital dermatitis in different housing systems relative to months in housing and flooring conditions

Housing System	Housing period (month)	Proportion of cows affected	Number of cows evaluated	Flooring Condition[1]	Proportion of cows affected	Number of cows evaluated
Cubicles	1	0.075	19,068	1	0.059	16,411
	2	0.11	2,673	2	0.12	2,723
	3	0.18	3,973	3	0.14	9,047
	4	0.18	9,381	4	0.16	19,930
	5	0.16	19,451	5	0.12	45,230
	6	0.20	6,292			
Straw yards	1	0.074	700			
	2	0.075	385			
	3	0.070	317			
	4	0.079	649			
	5	0.11	962			
	6	0.19	872			
Pasture	1	0.13	10,163			
	2	0.082	2,879			
	3	0.054	2,767			
	4	0.059	4,641			
	5	0.039	5,375			
	6	0.024	2,076			
Slatted or Loafing yards		0.14	767			

[1]Flooring condition: 1 = slippery, dirty surfaces with holes in concrete; 2 = even concrete, but slippery underfoot; 3 = uneven/sloping concrete; 4 = level concrete; 5 = perfect nonslippery, clean, and level surfaces.

Table 5.3 Predicted influence with standard error (SE) of housing situation (relative to pasture and flooring condition[1] (relative to floor 1) on the incidence of digital dermatitis

Housing situation	Housing period (month)	Predicted value	SE
Cubicle	1	-0.027*	0.010
	2	0.048*	0.021
	3	0.107*	0.019
	4	0.121*	0.014
	5	0.119*	0.012
	6	0.174*	0.012
Straw yard	1	-0.030NS	0.031
	2	0.027NS	0.046
	3	0.032NS	0.046
	4	0.038NS	0.034
	5	0.048NS	0.028
	6	0.11*	0.033
Slatted or loafing yard		-0.01NS	0.029
Flooring condition			
1 vs 5	-	-0.048*	0.009
2 vs 5	-	0.011NS	0.014
3 vs 5	-	0.008NS	0.009
4 vs 5	-	0.032*	0.007

[1]Flooring condition: 1 = slippery, dirty surfaces with holes in concrete; 2 = even concrete, but slippery underfoot; 3 = uneven/sloping concrete; 4 = level concrete; 5 = perfect nonslippery, clean, and level surfaces.
**P* < 0.05.

Table 5.4 Heritability (h^2) of DD and genetic (r_g) and phenotypic (r_p) correlations of DD with type traits plus their standard errors (SE)

Trait[1]	h^2	SE (h^2)	r_g	SE (r_g)	r_p	SE (r_p)	r_{p*}[2]	SE (r_{p*})
DD	0.11 (0/1 scale)	0.003						
	0.029 (normal)	0.007						
LOCO			-0.67*	0.08	-0.31*	0.003	-0.50*	0.005
RLS			0.15NS	0.11	0.08*	0.004	0.12	0.007
FA			0.03NS	0.11	-0.01*	0.004	-0.02*	0.007
L&F			-0.63*	0.08	-0.22*	0.003	-0.36*	0.005
BONEQ			-0.21*	0.10	-0.06*	0.004	-0.09*	0.007

[1]DD = digital dermatitis; LOCO = locomotion score; RLS = rear legs, side view; FA = foot angle; L&F = leg and feet composite; BONEQ = bone quality.
[2]rp* = transformed phenotypic correlations.
**P* < 0.05.

Table 5.5 Approximate genetic correlations ± SE among type traits, LS, production and fertility traits, and DD

	Trait[1]				
Trait[2]	LS	Milk	Fat	CI	NR56
LOCO	0.66 ± 0.02	-0.04 ± 0.03	0.22 ± 0.03	0.04 ± 0.03	0.02 ± 0.03
RLS	-0.32 ± 0.03	0.06 ± 0.03	-0.08 ± 0.03	-0.09 ± 0.03	-0.11 ± 0.03
FA	0.27 ± 0.03	-0.07 ± 0.03	0.04 ± 0.03	0.19 ± 0.03	0.14 ± 0.03
L&F	0.69 ± 0.02	-0.11 ± 0.03	0.12 ± 0.03	0.06 ± 0.03	0.07 ± 0.03
BONEQ	0.50 ± 0.03	-0.12 ± 0.03	-0.01 ± 0.03	0.07 ± 0.03	0.36 ± 0.03
LS		-0.24 ± 0.03	0.05 ± 0.03	-0.49 ± 0.03	0.39 ± 0.03
Milk			0.43 ± 0.02	0.27 ± 0.03	-0.44 ± 0.04
Fat				0.27 ± 0.03	-0.22 ± 0.03
CI					-0.34 ± 0.03
DD	-0.16 ± 0.02	-0.31 ± 0.02	-0.43 ± 0.02	-0.07 ± 0.02	0.48 ± 0.02

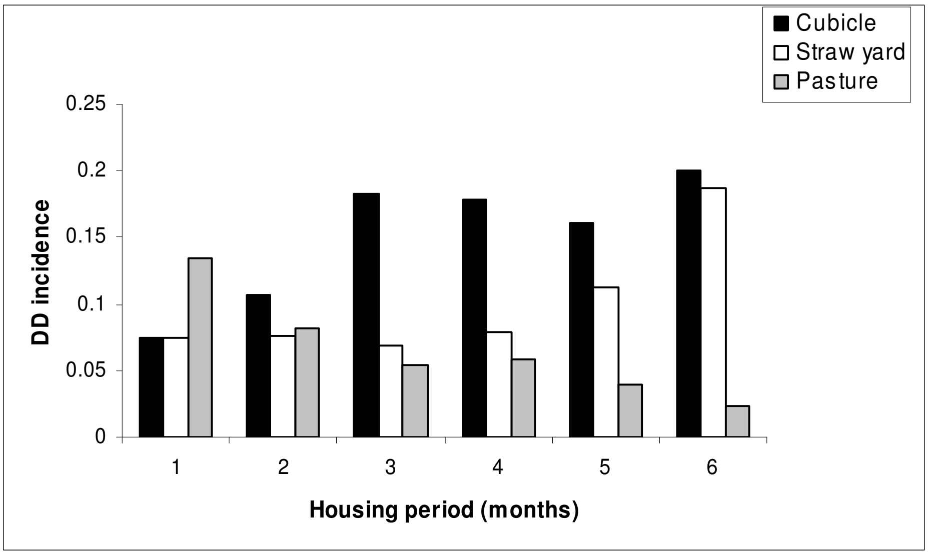
[1]LS = lifespan; CI = calving interval; NR56 = nonreturn after 56 d; DD = digital dermatitis.
[2]LOCO = locomotion score; RLS = rear legs, side view; FA = foot angle; L&F = legs and feet composite; BONEQ = bone quality.

Table 5.6 Approximate genetic correlations ± SE between type, DD, and fertility traits[1] at constant milk yield

Trait[2]	CI	NR
LOCO	-	-
RLS	-0.11 ± 0.03	-0.09 ± 0.03
FA	0.22 ± 0.03	0.12 ± 0.03
L&F	0.09 ± 0.03	0.02 ± 0.03
BONEQ	0.11 ± 0.03	0.34 ± 0.03
DD	0.015 ± 0.02	0.40 ± 0.02

[1]CI = calving interval; NR56 = nonreturn after 56 d.
[2]LOCO = locomotion score; RLS = rear legs, side view; FA = foot angle; L&F = leg and feet composite; BONEQ = bone quality; DD = digital dermatitis

Figure 5.1. Combined effect of housing system and housing period on digital dermatitis (DD) incidence



Black, white, and gray bars = incidence of DD in cubicles, straw yards, and pasture, respectively.

CHAPTER 6

GENETIC ASSOCIATION BETWEEN TIME SPENT IN CUBICLES AND LOCOMOTION TYPE TRAITS USING RANDOM REGRESSION MODEL

6.1 Summary

Changes in locomotion type traits associated with lameness in relation to time (months) spent in cubicles were estimated using a random regression model. The period of housing ranged from 1 to 12 months. Data were obtained from national type evaluation records of pedigreed Holstein-Friesian cows that calved from 2000 through 2006. With a minimum of 5 daughters per sire, the data set comprised 96,938 cows from 1,474 sires whose daughters were classified when housed in cubicles. The type traits evaluated were locomotion score (LOCO), rear legs, side view (RLS), foot angle (FA), bone quality (BONEQ) and leg and feet composite (L&F). Plots of the overall trend showed a steady decrease in the value of the traits with longer time in cubicles, indicating an antagonistic relationship between locomotion type traits and cubicle housing. The heritability estimates for the traits were all moderate apart from that of LOCO (0.097) in month1. Estimates of the genetic correlations of the traits between months of housing were all positive and decreased with increasing time. Generally, the results showed significant existence of a genotype x environment interaction, which suggests that modification of genetic evaluation procedures for these type traits on the basis of cubicle housing should be considered in the UK.

6.2 Introduction

Dairy cow housing systems vary across farms. Some cows are housed indoors all through the year particularly on farms with cows of high genetic merit for milk yield. In other farms, especially those in countries with less adverse weather conditions, cows are kept at pasture throughout the year. Most farms practice a two way system where cows are housed indoors during winter and turned out at grass during the summer period. In the United Kingdom, although the practice of zero-grazing is increasing (Haskell *et al*., 2006), housing of cows indoors during winter and outdoors in summer months is most common.

Housing is an important aspect of health and welfare in dairy cow management. Haskell *et al*. (2006) noted that housing cows on concrete affects the health of legs and feet because of its unyielding nature. The use of cushioning surfaces as flooring on concrete, such as softer layers of rubber, has been found to reduce leg and claw problems (Vokey *et al*., 2001) but this effect was not found for mats and mattresses (Chaplin *et al*., 1999). In the UK, Murray *et al*. (1996) and Kossaibati and Esslemont, (2000) reported that claw horn lesions accounted for between 35 and 60% of lameness recorded on free-stall housed herds with summer grazing. An evaluation of the seasonality of veterinary treatment for lameness from the UK National Animal Disease Information Service (NADIS) database showed a peak rise in cases of sole ulcer during late winter (Laven and Lawrence, 2006) which corroborates the reports of Eddy and Scott, (1980) and Rowlands *et al*. (1985) that sole ulcers increased toward the end of the housing period. The authors attributed the rise in sole ulcers to longer indoor housing and cows spending significantly more time on concrete even when outdoors. The study also reported that most UK farms now have endemic digital dermatitis, which persists into the grazing period. Generally, the authors found no significant difference in the seasonality of lameness even when winter housing was compared to the summer grazing period, suggesting that lameness can occur in any period.

Results of this nature indicate the benefits of identifying genotypes that are more resistant to lameness either for specific housing periods or across a range of environment. Haskell *et al*. (2007) noted that farm environment affects the production and health of cows and that genotypes may respond differently to different types of farm environment. This implies that sires may be genetically similar or rank differently in different environments based on the performance of their daughters. The variation in the performance of different genotypes in different environments is referred to as genotype x environment (GxE) interaction (Falconer and Mackay, 1996). According to Haskell *et al*. (2007), estimating the degree of GxE allows identification of sires as either specialists (those ranking highly in a particular environment) or generalists (those with similar rankings across environments). Some researchers have reported a scaling effect in which no re-ranking of sires occurred (Boettcher *et al*., 2003; Kearney *et al*., 2004) whereas others have observed re-ranking of sires between different environments (Kolver *et al*., 2002; Hayes *et al*., 2003).

Selecting genotypes with good locomotion traits suited to intensive housing environments could further reduce lameness and hoof problems in dairy cows. The availability of such information will enable breeders to select for robust cows that will be less affected by lameness both in future and in current housing management practices. Most studies evaluating GxE have concentrated on production and fertility traits. Little research has been geared towards the effect of GxE on health traits, and the few documented studies have focused mainly on somatic cell count (Castillo-Juarez *et al*., 2000; Calus *et al*., 2006; Kearney *et al*., 2004), mastitis (Pryce *et al*., 1999) and longevity (Haskell *et al*., 2007). Studies exploring the existence of GxE for locomotion traits are rare in the literature. Boettcher *et al*. (2003) found no interaction between cows in grazing and a control environment for mammary system. Generally, data on the length of time cows spend in different housing environments are not available. However, in the UK, field officers record information on the amount of time cows have spent in cubicles at the time of type classification, making it possible to estimate the association between period of housing and locomotion type traits. Cows spending 6 months or more in cubicles are assumed to be under an intensive system of management.

Random regression models (RRM) are used for analyzing longitudinal data where observations for a trait are collected several times during the course of an animal's life (Hill and Brotherstone, 1999). Many traits measured on dairy cattle including linear type scores have repeated records across time with varying correlations between records (Wall *et al*., 2005) at the sire level. Analysis of such records with RRM gives an indication of changes in genetic variances across the time trajectory (Schaeffer and Dekkers, 1994) and allows selection of animals to alter the general patterns of response over time (Schaeffer, 2004). The use of RRM to study genotype by environment interaction could indicate changes in the genetic value of animals over time which might cause re-ranking of animals. Since genetic parameters are estimated on an environmental gradient, GxE can be identified more precisely based on the genetic correlations between different points on the environmental axis (Pégolo *et al*., 2009).

6.3 Objectives

The objectives of this study are (1) to estimate the influence of GxE on locomotion and leg and feet traits scored in cubicles using a sire random regression model; (2) to calculate genetic correlations between the same traits scored in different months of housing.

6.4 Materials and Methods

6.4.1 Data

The UK national type evaluation records of first-lactation pedigreed Holstein-Friesian cows that calved between 2000 and 2006 were used for this analysis. Originally, the data comprised 97,511 records of cows, type classified in cubicles. Selecting sires with a minimum of 5 daughters resulted in a data set that comprised 96,938 cows, daughters of 1,474 sires classified when housed in cubicles.

Five locomotion type traits were analysed. The traits include locomotion score (LOCO), rear legs, side view (RLS), foot angle (FA), and bone quality (BONEQ) scored on a scale of 1 to 9 denoting extreme biological values, and leg and feet composite (L&F) measured on a continuum subjective scale of 65 "poor" to 95 "excellent". A brief description of the traits with their means and standard deviations is given in Table 6.1. Cows were between

21 and 59 months of age at inspection. Herd visits were made once every 10 months to avoid classifying cows more than once per lactation.

6.4.2 Housing Information

Information on housing is recorded based on the amount of time cows spend in each housing type and the flooring condition where classification takes place, and this is collected at the same time as the cows are type-classified. The time spent in cubicles by cows ranged from 1 to 12 months. Detailed information on housing is given in chapter 4.

6.4.3 Statistical Analysis

Each trait was first adjusted for differences in the range of scoring by field officers by scaling records so that individual field officer standard deviations were equal to the mean standard deviation of all field officers (Brotherstone, 1994). A prior analysis considered records of cows that had spent a minimum of 3, 4, 5 and 6 months in cubicles but analysis was difficult with such small data sets. As a result, all records collected over the 12 monthly periods were used for this analysis.

Variance and covariance components for the slope and intercept of the regression of each trait on time in months were estimated with a RR sire model fitted with orthogonal polynomial of order 2 using ASREML software (Gilmour *et al*, 2000). Herd-year-visit was confounded with flooring condition. As a result it was included in the model as a random effect. The RR model fitted was:

$$Y_{ij} = \mu + hyv + \sum_{n=1}^{2} \chi_n age^n + \sum_{n=1}^{2} \beta_n stage^n + \delta.phols + moc + hfloor + \sum_{m=1}^{2} \alpha_m \theta_m (mo) + \sum_{m=1}^{2} \lambda_{jm} \theta_m (mo) + e_{ij}$$

where,

Y_{ij} = type trait record measured on cow i of the jth sire; μ = overall mean; hyv = random herd-year-visit effect; χ_1 and χ_2 = linear and quadratic regression coefficients of traits on the age of cow i at classification; β_1 and β_2 = linear and quadratic regressions of traits on stage of lactation (stage) of cow i at classification; δ = linear regression of traits on the proportion of Holstein genes (*phols*) in animals; *moc* = month of calving of cow; *hfloor* = floor condition when cow i was classified; α_m = fixed regression coefficients;

λ_{jm} = random regression coefficients for j[th] sire; $\theta_m(mo)$ = m[th] orthogonal polynomial evaluated at month of housing; e_{ij} = residual random error.

The genetic variance for all traits in each month and covariance components between different months for individual traits were then calculated from the variance-covariance matrix of the intercept and slope. Heritability estimates for individual traits in each month were obtained using the formula below:

$$h_t^2 = {4\sigma_{st}^2}/{\sigma_p^2}$$

where h_t^2 = heritability of trait at time t, σ_{st}^2 = sire genetic variance at time t, σ_p^2 = phenotypic variance (σ_{st}^2 + residual variance from the sire model), t = month (1 … 12)

Three residual error variance classes (REC) were fitted in the model to account for measurement error variation in the length of time cows have stayed in a particular environment. REC = 1 assumed that the residual variance was constant across all months for all the traits i.e. measurement error was homogeneous across months, while REC = 2 allowed the residual variance to differ between month one of housing and the remaining 11 months. REC = 3 considered differences in residual variance between months one, two and the other months. Significant differences between the model with a constant REC and the others were tested using a χ^2-test on the log-likelihoods.

6.5 Results

6.5.1 Fixed and Random Regression Analysis

In general, age of cow at inspection and stage of lactation at inspection were significant ($P < 0.05$) for all traits measured. Mean proportion of Holstein genes was also significant ($P < 0.05$) for all traits. Months in housing removed a significant ($P < 0.05$) amount of variation from all the traits except for LOCO. Figures 6.1a, b, c, d and e give the fixed regression curves (overall trend) for all the traits for cows scored in cubicle housing. The trend of the fixed curves for locomotion, rear legs, side view, foot angle, and leg and feet composite indicated higher values at the beginning of the trajectory which deteriorated steadily till the end of the trajectory. (Note that higher value for RLS means more sickled hock). However, the fixed trend curve for BONEQ showed an increase towards the end of the housing period, suggesting that flatter, more refined bones were associated with longer periods of housing in cubicles.

6.5.2 Measurement of Residual Variance Error

Table 6.2 gives the number of records in each month of housing. Comparing the single error class model to models with more than 1 error class, the likelihood ratio test (LRT) for LOCO, RLS, L&F and BONEQ showed no significant difference between the models ($P < 0.05$), indicating that a constant error variance is suitable for these traits (Table 6.3). Thus, the residual variances were not partitioned further. FA had a consistent significant increase in logL as the number of error classes increased. For FA, 3 REC appeared to be the best fitting model of those compared. However, for consistency of results across all traits estimates of heritability, genetic variances and genetic correlations were based on the model with a constant error variance. Log-likelihoods (logL) for model 2 and 3 are relative to logL for model 1 which was set to zero.

6.5.3 Genetic Variances and Correlations

Figures 6.2a, b, c, d and e show the genetic variances of all the traits. The genetic variances increased from the start to the end of time in cubicle housing for all the traits. This could be a result of the small number of records towards the end of housing period. The genetic variance for BONEQ was constant between month 2 and 6, suggesting no association between BONEQ and time the sires' daughters spent in cubicles.

Genetic correlations (r_g) of all traits at 3 monthly intervals are presented in Tables 6.4a, b, c, d, and e. The genetic correlations between months of housing followed a similar pattern for all traits. All r_g were positive and decreased with increasing housing time. Generally, the results showed little evidence of different genes operating across the months as r_g were all high (>0.80), except for FA where the r_g between month1 and 12 and 3 and 12 were 0.62 and 0.76, respectively. In consequence, FA gets shallower with longer housing period. However, as standard errors were not available, no definite conclusions on GxE can be drawn from the genetic correlations.

Both the sire and sire by month effect for all traits were significantly different from zero, indicating the existence of a genotype x environment interaction for these traits. This shows changes in the type scores of sire daughters across months spent in cubicles. Changes in the performance of sire daughters with time for two traits (locomotion and leg and feet score) for selected bulls are shown in figure 6.3a(i), (ii) and 6.3b(i), (ii). Two sires each representing bulls of extreme performance were chosen for the two traits to illustrate the differences in sire profiles in terms of their daughters performance with time spent in cubicles. Figures 6.3a(i), (ii) and 6.3b(i), (ii) indicate that there are differences between bulls and between locomotion type traits for bull daughters depending on time housed in cubicles. For instance, compared to the average, daughters of some bulls show improved locomotion and better leg and feet score, while the daughters of others show poorer locomotion and leg and feet score with increasing time spent in cubicles.

6.5.4 Heritability Estimates

Apart from the heritability of LOCO (0.097) in month 1, the type traits generally had moderate h^2 estimates for all months (Table 6.5). The h^2 of traits consistently increased across months except for FA which remained constant from month 1 to 5 and BONEQ which decreased in month 2 but then remained constant up to month 6. This is due to the constant genetic variance observed in these months for BONEQ. The heritability of FA in all the months was lower than other traits apart from LOCO in months 1, 2 and 3. The heritability of the leg and feet composite was unexpectedly high towards the end of cubicle housing ranging from 0.31 in month 9 to 0.39 in month 12.

6.6 Discussion

In random regression analysis, it is normal to investigate various orders of fixed polynomial in order to find the best fitting trend curve for the traits of interest. By visually inspecting plots of the raw type traits data analysed in this study over time I ascertained that a quadratic trend curve was most appropriate for all traits. However, I suggest that this analysis is repeated when more data is available. It is possible that with more data recorded for these traits towards the end of the housing period, a higher order polynomial might be more suitable.

6.6.1 General Trend of Type Trait Curves

The overall fixed trend for the traits showed explicitly that cubicle housing is antagonistic to the health of leg and feet traits. The cows had poorer locomotion, more sickled hocks, lower foot angle, poorer leg and feet score and lower bone quality values, all of which are associated with increased lameness (Fregonesi, 1999; chapter 4). The high BONEQ values seen towards the end of the trajectory is unclear but may suggest that cows become resistant to the abrasive and unyielding nature of the solid concrete floors over time, which then exerts little or no effect on the quality of the bones. Alternatively, it could be that cows with flat and refined bones are kept longer indoors as a result of their high yielding capacity for milk.

6.6.2 Genetic Parameters and Variances

Estimates of genetic parameters for locomotion traits based on months of housing have not been reported in the literature before now. Uribe *et al*. (2000) reported that some conformation traits including rear leg set were affected by age more than others.

The results indicate possible differences in genetic variances across months for all traits, showing that there are differences between sires in their daughters' type scores with respect to the time spent in cubicles. The profile of genetic variance for LOCO and L&F, however, followed a similar trend. This is not surprising as these traits have been reported to be highly correlated (Paget *et al*., 2003, van der Waaij *et al*., 2005; chapter 4). If genetic variance varies across months in cubicles, it might be necessary to account for this in order to obtain the best estimate of a daughter's performance at any specific month. This may be more appropriate for cows that are managed intensively.

6.6.3 Heritability Estimates

Heritability estimates for the traits tended to be moderate particularly towards the end of the housing time. Fatehi *et al*. (2003) recorded similar heritability values for the traits in both tie and free stall although their estimates were not derived on a monthly basis. For example, they reported heritability estimates of 0.12, 0.21, 0.17 and 0.29 in tie stall and 0.11, 0.20, 0.15 and 0.24 in free stall for FA, RLS, L&F and BONEQ, respectively.

Brotherstone (1994) reported a heritability estimate of 0.32 for L&F with a sire model. In this study, L&F had the highest heritability values, ranging from 0.28 (8 months in cubicle housing) to 0.39. The heritability of BONEQ was more consistent across months. As the error variances were constant across months for all traits, the heritabilities followed the profile of the genetic variances. Although the h^2 values were higher towards the end of housing, the estimates may be biased due to a small number of records at these points which could lead to unpredictable genetic variances. Others have reported a similar increase at the end of the trajectory with lactation studies (Berry *et al*., 2003; Wall *et al*., 2005) and beef cattle weight records (Pégolo *et al*., 2009).

6.6.4 Genotype x Environment Interaction

The presence of a GxE in this study suggests that sires differ in the response of their daughters to changes in locomotion type scores with respect to months in cubicle housing. This means that, compared to the average, some sires produce daughters whose legs and feet are less affected by the time in cubicle housing, whereas the legs and feet of daughters of other sires deteriorate with time in cubicles. Differences in sire performance have also been reported for production traits (Hayes *et al*., 2003), fertility (Oseni *et al*., 2004) and longevity (Haskell *et al*., 2007). The presence of environmental sensitivity presents an opportunity for farmers to choose sires based on their specific farm type and that this may improve dairy cow welfare since animals that perform well in terms of health and production are chosen (Haskell *et al*., 2007). However, such a selection might be unreasonable as well as very costly and time consuming (Hedi *et al*., 2009). Perhaps, the appropriate method might be to select bulls on a combination of their average performance across all months and the environmental sensitivity. With this, the results here also indicate that farmers can select sires with high genetic merit for locomotion type traits for breeding cows that are better able to withstand the unfavourable nature of cubicle housing over time. Again as Holstein UK includes information on housing as a part of its routine type classification scheme, including information on the number of months each cow has spent in cubicles at the time of classification in the national evaluation model may result in more accurate breeding values for bulls since these traits demonstrated a GxE.

6.7 Conclusions

Environmental changes, in addition to genetic factors influence legs and feet traits. The results obtained in this study support the fact that cubicle housing is unfavourable to locomotion type traits. The overall trend showed that with longer time in cubicles cows had poorer locomotion, more sickled hocks, lower FA, poorer L&F and thicker, coarser BONEQ. There were differences in the profiles of the genetic variances but LOCO and L&F showed a similar trend. There was significant evidence of a genotype x environment interaction for all the traits, suggesting variation between sires in the sensitivity of their daughters to cubicle housing with time.

Table 6.1 Description of traits included in the analysis

		Score		Cubicle	
Type trait	Abbreviation	1	9	Mean	SD
Locomotion	LOCO	Lame	Normal	5.34	1.44
Rear legs, side view	RLS	Straight	Sickled	5.18	1.35
Foot angle	FA	Low	Steep	5.21	1.37
Bone quality	BONEQ	Thick and coarse	Flat and refined	6.18	1.31
		65	95		
Leg and feet composite	L&F	Poor	Excellent	79.61	5.09

Table 6.2 Number of records in each month of cubicle housing

Month	Number of records
1	34292
2	5737
3	6843
4	13585
5	26543
6	6234
7	1824
8	169
9	-
10	13
11	95
12	1603

Table 6.3 Change in log-likelihood (logL) of the error variances for the type traits

Change in logL (x2)		
Trait	2REC	3REC
LOCO	1.5	-
RLS	0.0	-
FA	8.0	12.5
L&F	0.0	1.0
BONEQ	0.4	-

LOCO = locomotion score, RLS = rear legs, side view, FA = foot angle, L&F = leg and feet composite, BONEQ = bone quality. REC = Residual error class

Table 6.4a Genetic correlation (r_g) between different months of scoring for locomotion

1	3	6	9	12
1 -	0.98	0.94	0.89	0.82
3	-	0.99	0.96	0.89
6		-	0.99	0.96
9			-	0.98
12				-

Table 6.4b Genetic correlation (r_g) between different months of scoring for rear leg side view

	1	3	6	9	12
1	-	0.99	0.94	0.88	0.83
3		-	0.98	0.95	0.90
6			-	0.95	0.94
9				-	0.93
12					-

Table 6.4c Genetic correlation (r_g) between different months of scoring for foot angle

	1	3	6	9	12
1	-	0.98	0.88	0.81	0.62
3		-	0.98	0.87	0.76
6			-	0.97	0.92
9				-	0.98
12					-

Table 6.4d Genetic correlation (r_g) between different months of scoring for leg and feet composite

	1	3	6	9	12
1	-	0.99	0.94	0.89	0.84
3		-	0.98	0.95	0.91
6			-	0.96	0.96
9				-	0.99
12					-

Table 6.4e Genetic correlation (r_g) between different months of scoring for bone quality

	1	3	6	9	12
1	-	1.0	0.98	0.94	0.90
3		-	0.99	0.96	0.93
6			-	0.99	0.94
9				-	0.99
12					-

Table 6.5 Heritability (h^2) estimates for the type traits scored in cubicles at different months

Month	LOCO	RLS	FA	L&F	BONEQ
1	0.097	0.13	0.11	0.17	0.27
2	0.10	0.14	0.11	0.18	0.26
3	0.11	0.15	0.11	0.19	0.26
4	0.12	0.16	0.11	0.21	0.26
5	0.13	0.17	0.11	0.22	0.26
6	0.14	0.19	0.12	0.24	0.26
7	0.15	0.20	0.13	0.26	0.27
8	0.17	0.21	0.14	0.28	0.27
9	0.18	0.23	0.16	0.31	0.27
10	0.20	0.25	0.17	0.33	0.28
11	0.22	0.27	0.19	0.36	0.28
12	0.24	0.30	0.20	0.39	0.29

LOCO = locomotion, RLS = rear legs, side view, FA = foot angle, L&F = leg and feet, composite, BONEQ = bone quality

Figure 6.1a Fixed regression curve for locomotion score

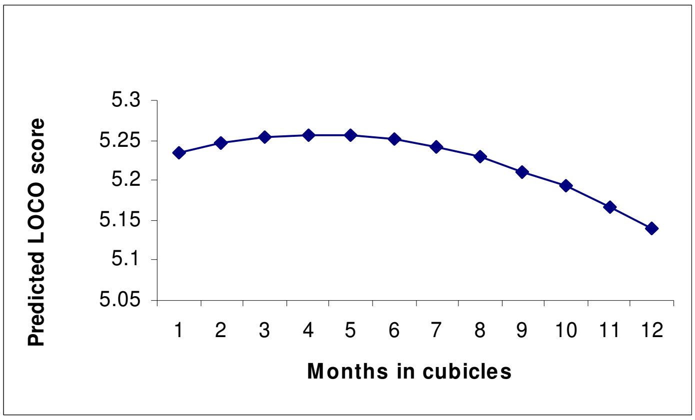


Figure 6.1b Fixed regression curve for rear legs, side view

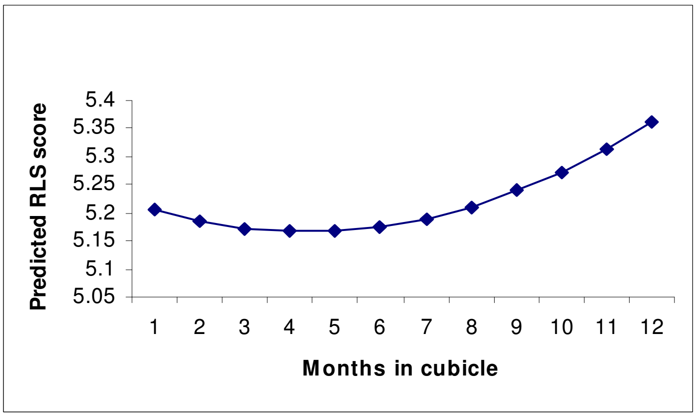


Figure 6.1c Fixed regression curve for foot angle

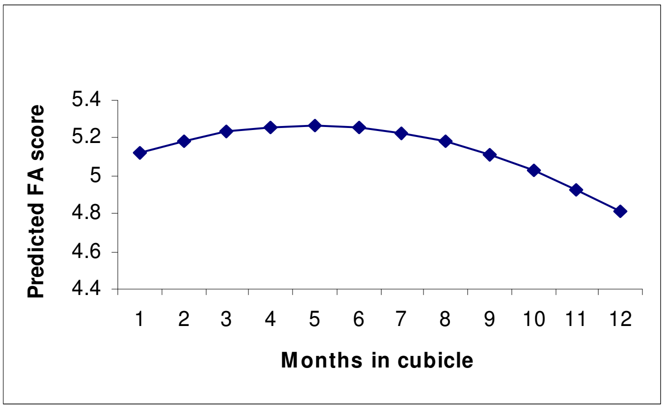


Figure 6.1d Fixed regression curve for bone quality

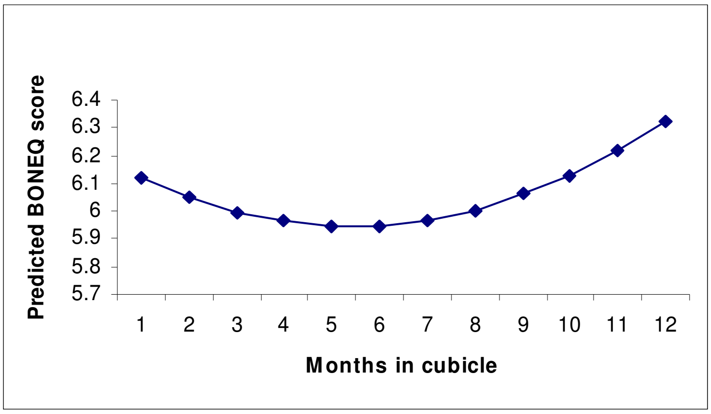


Figure 6.1e Fixed regression curve for leg and feet composite

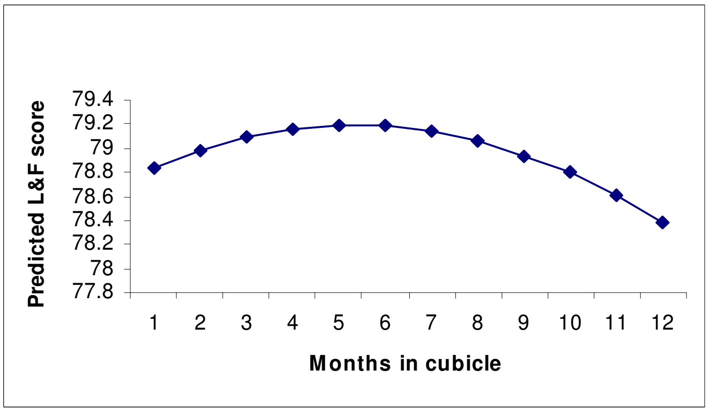


Figure 6.2a Genetic variance for locomotion score

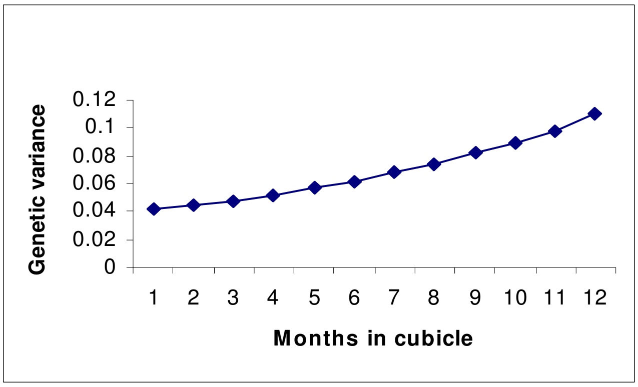


Figure 6.2b Genetic variance for rear legs, side view

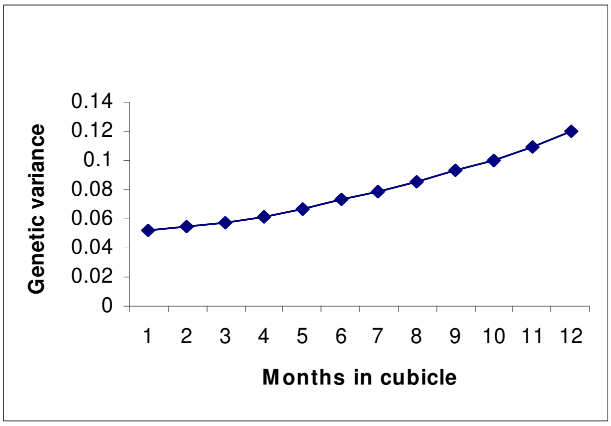


Figure 6.2c Genetic variance for foot angle

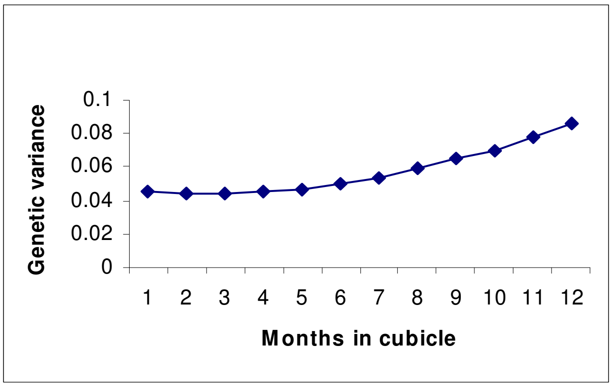


Figure 6.2d Genetic variance for bone quality

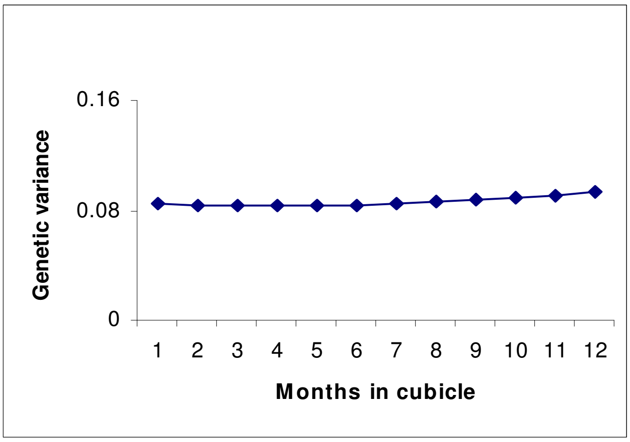


Figure 6.2e Genetic variance for leg and feet composite

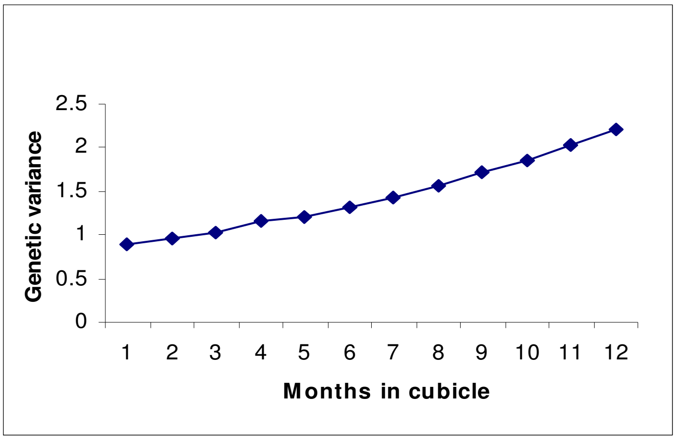


Figure 6.3a(i) Differences in sire profiles for locomotion score in terms of daughters performance with time in cubicles (extreme positive bulls)

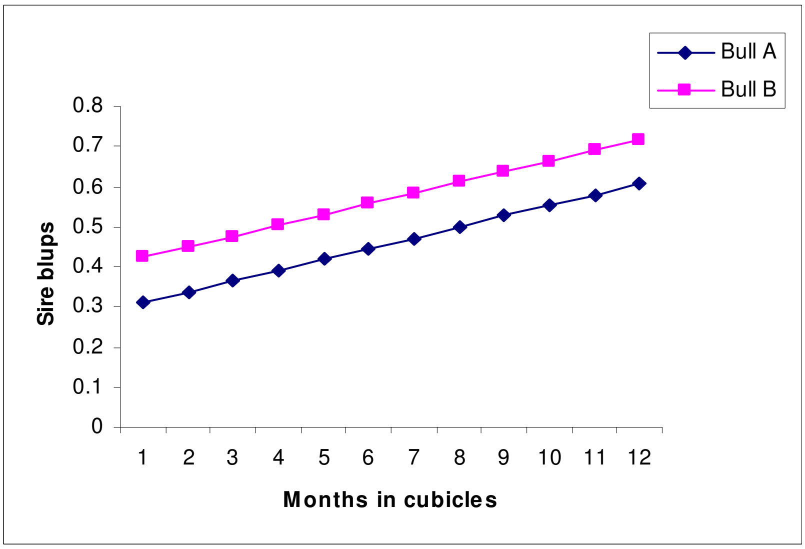


Figure 6.3a(ii) Differences in sire profiles for locomotion score in terms of daughters performance with time in cubicles (extreme negative bulls)

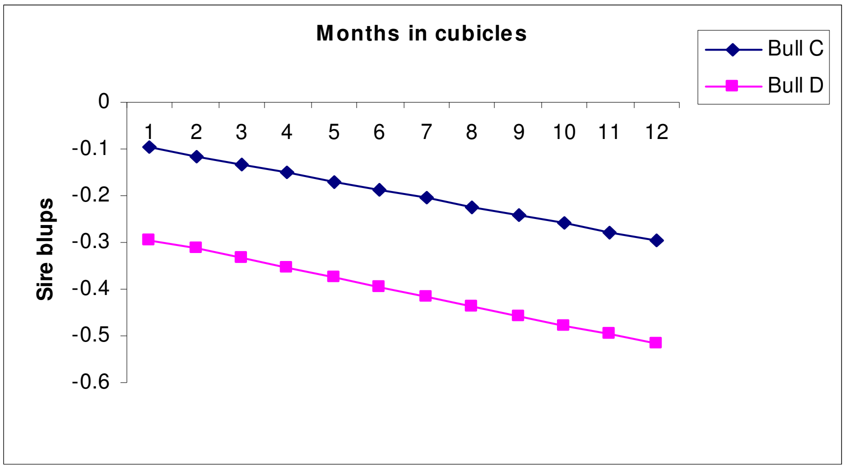


Figure 6.3b(i) Differences in sire profiles for leg and feet composite in terms of daughters performance with time in cubicles (extreme positive bulls)

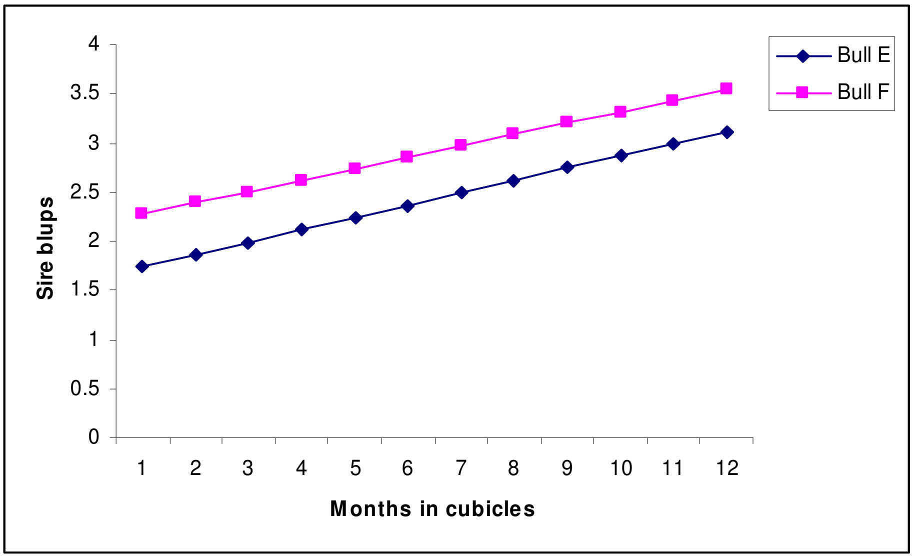
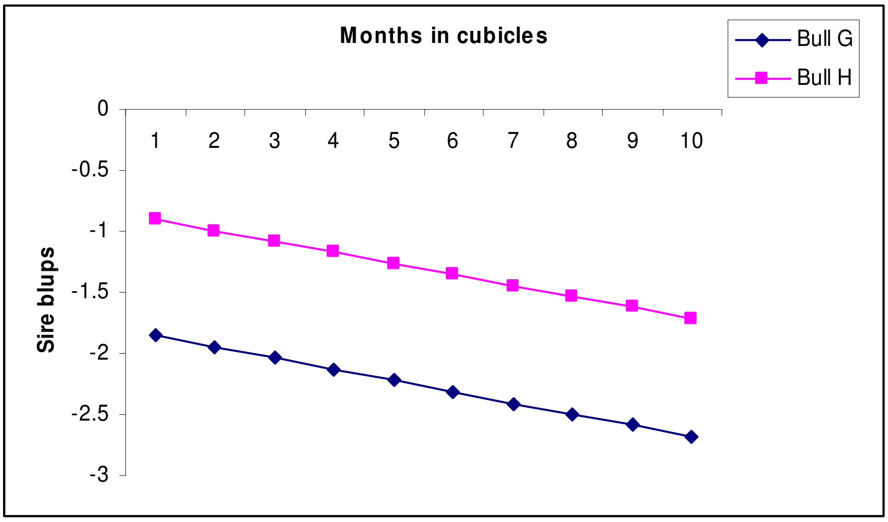


Figure 6.3b(ii) Differences in sire profiles for leg and feet composite in terms of daughters performance with time in cubicles (extreme negative bulls)



CHAPTER 7
GENERAL DISCUSSION

7.1 Introduction

There has been a growing interest in the genetic improvement of health traits in recent years in order to counteract the negative impact of intense selection for production on the welfare and longevity of the dairy cow. Lameness has long been recognized as one of the greatest welfare problems of the dairy cow (Greenough and Weaver, 1997) and has been associated with involuntary culling, severe pain, reduced reproductive performance, reduced longevity, decreased milk production and other diseases. These undesirable and unacceptable consequences continue to demand research into the numerous factors (environmental and genetic) related to lameness in order to avert or at least minimize future deterioration by developing better preventative regimens. To this effect, I investigated various risk factors including milk yield losses associated with both heifers and later lactation cows (chapter 3) using locomotion score data from an experimental farm where locomotion was scored weekly on a scale of 1 to 5 on all cows. This analysis showed that the most important variables influencing locomotion in heifers and cows are management regime and time of year when locomotion scoring took place. Cows housed all year and fed a high-concentrate diet were more prone to locomotive problems than those managed in a more extensive system. The study also indicated that locomotive problems adversely affect the milk production of dairy cows (but not during the 1st lactation), and that high-yielding cows are more prone to problems. Given that high yielding cows are more prone to lameness and that management practices (intensive and extensive) accounted for significant variation in the locomotion of both heifers and later lactation cows (chapter 3), a genetic evaluation of locomotion and its associated type traits was performed for cows managed in different housing systems using national data (chapter 4). Results from chapter 4 indicated that cows on pasture had favorable type trait scores compared with cows in other housing systems and that nonslippery, level floor surfaces were associated with fewer locomotion problems and better legs and feet score (L&F). Locomotion had a high genetic correlation with L&F and a moderate genetic association with foot angle (FA) and mammary (MAMM), suggesting that cows with higher scores for L&F and MAMM and with steeper FA had genetically better locomotion. On the basis of the genetic parameters, the study revealed that bone quality (BONEQ) could be included in a selection index as a predictor of longevity. In the UK, digital dermatitis (DD) is one of the four most common diseases causing lameness in dairy cows (Hedges *et al*., 2001). In chapter 5, I evaluated the association between DD and housing and lameness-related type traits as well as the approximate genetic correlations between DD and lifespan, production and fertility traits using sire EBVs. In this chapter, I also estimated the approximate genetic correlations between locomotion traits and lifespan, production and fertility traits. Results showed reduced incidence of DD for cows at pasture compared with cows in other housing systems and those with flatter and more refined bones, higher locomotion score, and better leg and feet composite. Estimates of genetic parameters indicated heritable variation of DD among cows and moderate genetic associations between DD and lifespan and production traits. This result demonstrated that DD is a useful trait to be included in a selection index for improved cow resistance to the disease and increased longevity. The genetic associations between locomotion type traits and lifespan ranged from moderate to high, whereas, in general, these type traits had low correlations with production and fertility.

With a random regression model, I analysed changes in type traits associated with lameness in relation to time (months) that cows spent in cubicles. There was some evidence of genotype x environment interaction, demonstrated by the presence of different genes operating across the months. However, results indicated the existence of genotype x environment interaction for these traits, suggesting differences in the performance of sire daughters with time in cubicle housing.

7.2 Locomotion Scoring Systems

In the UK and in many other dairy countries, locomotion score is recorded both at farm and national levels which acknowledges its use both as a management and a selection aid. A variety of locomotion scoring systems have been developed by various researchers many of which are difficult to use and require the farmers to be adequately trained in their use. Developing a simple, but effective locomotion scoring system would enable ease of use by various scorers which would allow accurate and sufficient data to be collected. A simple system would also enable continuous scoring of individual cows across several lactations allowing a more precise study of the association between locomotion and management as well as other traits of economic importance like production, body condition score and persistency. According to Defra (2007), there is a significant range in the incidence and prevalence of lameness between farms, indicating that some farmers manage lameness better than others.

The locomotion scoring system in use at Crichton Royal Farm (chapter 3) was designed for ease of adoption by many farmers, providing useful, reliable and readily available information on herd level of lameness. Such a system enables as many farmers as possible to tackle lameness problems which could significantly reduce the incidence on farms. Programmes targeting farm specific cases of lameness could be more effective than a generic approach.

7.3 Analysis of Digital Dermatitis (DD)

In this thesis, DD was recorded as a discrete variable on a 0/1 scale and was analyzed using a linear animal model and then transformed to an underlying normally distributed scale. Threshold models are used in analyzing discrete characters with assumed underlying continuous liability. Linear and threshold models have been used for the genetic analysis of categorical traits with the assumption of an underlying normally distributed liability or incidence (Mrode, 2005). Advantages of threshold over linear models have been shown with simulated data with no fixed effects and a constant or variable number of offspring per sire (Meijering and Gianola, 1985). The advantage of the threshold model increased with a decrease in the incidence and heritability of the binary trait in their analysis, implying that the threshold model might be more appropriate for traits with low incidence and low heritability. However, variable results have been obtained with field records ranging from similarity of both models to superiority of linear over threshold models and vice versa.

DD had a low heritability (0.011) and a low incidence (0.12) in this study. Therefore, it is possible that a threshold model would have been a better method for analyzing this disease trait. However, the application of a threshold model (results not presented) gave a lower heritability estimate (0.0086) compared with that from a linear model. I assumed this could be due to varying incidence of DD with herd-year-visit. Meijering and Gianola (1985) reported that two major disadvantages of threshold models are that of computational demand and poor robustness. Since threshold models are used to relate a hypothetical underlying continuous scale to the outward discrete observations, then transforming the outcomes of a linear model to underlying normally distributed values would be assumed to conform to expected outcomes from a threshold model. In the UK, calving ease for beef cattle is currently being evaluated as a linear trait although the trait is strictly categorical (Matilainen *et al.*, 2009).

7.4 Genetic Correlations from Sire EBV

In chapter 5, estimates of approximate genetic correlations were made among lifespan, lameness-related type traits, production and fertility traits as well as between DD and lifespan and production and fertility traits using sire EBV. If EBV were true breeding values, they would then give an estimate of the true genetic correlations. However, EBVs are estimates of the genetic merit of bulls and different bulls have different reliabilities. Therefore, a straight forward correlation of EBV may be biased. To partly account for this, the EBV are de-regressed to adjust for the reliability of the proofs before estimating genetic correlations or better still correlations are adjusted for the reliabilities after being estimated from EBV as performed in this thesis. In future, work is required to re-estimate these correlations from phenotypic records (these records were not available to me during this study). This would give a more robust estimate of the strength of the associations between these traits.

7.5 Impact of Research on the Dairy Industry

Differences in locomotion scoring systems coupled with different husbandry practices have resulted in inconsistent research outcomes in terms of lameness incidence and associated risk factors both at farm and national level. The influence of lameness on milk production levels on farms has also varied. This has made it difficult for researchers to develop a robust plan to effectively and efficiently minimize lameness in herds. With a simple, easy to use scoring system as described in this thesis, farmers routinely identify lame cows. Not only will this be more cost effective to the farmers in terms of data

collection but will also lead to prompt and quicker treatment of lame cows with an increase in the overall farm efficiency.
One of the significant factors that affected locomotion score in my study (chapter 3) is time of year when cows were locomotion scored, indicating seasonality of lameness occurrence. This would suggest that evaluating lameness at specific seasons of the year would be helpful in identifying seasonal risk factors for the disease. In addition this would allow farmers to implement precautionary measures at such times for reduced incidence of lameness such as avoiding cows from walking very long distances on firm tracks during summer.

Body condition score (BSC) and body weight (BW) reflect body energy content, and body size and shape of an animal, respectively. Both traits (BW and BCS changes) indicate the rate of body tissue mobilization, and high metabolic rate has been associated with decline in health and fertility of dairy cows. Reduced body weight affected the locomotion and milk yield of cows in this thesis. By implication, thin cows are more prone to locomotion problems and hence produce less milk. This reinforces the suggestion of Coffey (2003) that selection which leads to thinner cows may not be acceptable in future. Similarly, high and very low body conditioned cows had increased locomotion problems and also produced less milk. It may then suggest that the rate of mobilization for body fat and protein reserves is high for these two groups of cows as energy input may not be commensurate with energy demand for output.

Despite the advantages of pasture rearing over indoor housing in terms of lameness incidence as reported in the literature and within the context of this thesis, switching from indoor housing to pasture management may not be a practical option for many producers. Cows at pasture produce less milk and there may be a decline in fertility due to weight loss and prolonged negative energy balance post-calving as a result of low energy intake. In Ireland, Dillion and Buckley (1998) reported an overall infertility rate of 6% for medium genetic merit cows and 25% for high genetic merit cows reared on pasture. In this thesis, I noted a higher persistency for average yielding cows compared to high producing cows, irrespective of housing system. Based on this, profit might be greater for farmers in terms of reduced mobility problems and increased milk yield if cows could be maintained at an average framed body size through selection and management. Ideally, there should be a balance between what is best for health and production and what may predispose to problems. Interestingly, I did not detect any significant association between genetic groups (select versus control cows) and locomotion score. This emphasizes the importance of good management (as observed with Critchon Royal farm) in reducing lameness incidence.

Selection decisions are still likely to continue to favour yield in future, but breeding for improved lameness-related type traits and increased resistance to digital dermatitis could be useful in preventing a decrease in the lifespan and in the quality of life of dairy cows. This is explained by the heritability estimates and the genetic and phenotypic correlations among type traits and between type traits and DD and longevity obtained in this thesis. The result raises a high possibility of BONEQ being used in a multi-trait index for selection of dairy cows in the UK and that such selection could have a positive correlated response in longevity which will be a desirable outcome for UK producers, while also reducing the negative impact of dairying on the environment.

7.6 Future Work

7.6.1 Association between Lameness and Milk Yield

Despite the conflicts from research outcomes on the exact cause-and-effect between lameness and milk yield, more reports have indicated that high levels of milk production are associated with high locomotion problems with a resultant decrease in milk production (chapter 3, Deluyker *et al*., 1991; Green *et al*., 2002; Defra, 2007). However, this conclusion was made based on small data sets generated mostly from research farms and to my knowledge no study has examined this association with national records. Although the inference is reliable and is expected to apply to the general dairy cow population, it is desirable in future to determine the association between milk yield and lameness from large data sets recorded at national levels with more detailed locomotion scoring system. This will provide more reliable estimates of the association between lameness and milk yield. Such a study might also explain the failure to detect any decrease in milk yield of heifers due to locomotion defects in this thesis. Unfortunately, locomotion scoring at national level is currently done only on first-lactation heifers. However, Holstein UK also classify later lactation cows which are highly selected sub-sets of each herd. Analysing such data might give more information on the relationship between milk yield and lameness for multiple lactation cows.

7.6.2 Persistency

Earlier studies have suggested that lactation curves allow detection of exact times of milk yield losses (Sogstad *et al*., 2007) and that the decreases in milk yield should be calculated as deviations from daily yield lactation curves (Barkema *et al*., 1994). In chapter 3, results indicated significant differences in the shape of lactation curves of cows lame before peak yield, after peak yield and those never lame throughout lactation and sound cows had a higher persistency than those lame before peak yield (high yielding cows). Haile-Mariam *et al*. (2003) noted that cows with lower peak yield and greater persistency experience less energy imbalance at the same total yield and thus less reproductive and health problems than cows with higher peak yield. The shape of the lactation curve determines lactation persistency and according to Dekkers *et al*. (1998) and Coffey (2003) persistency has an impact on feed cost, health and reproductive traits, and hence, profitability. Thus, the possibility of including persistency in sire evaluation programs as an additional measure for reducing locomotion problems is possible. Studies have estimated genetic correlations between persistency and survival, health and fertility traits (Haile-Mariam *et al*., 2003; Jakobsen *et al*., 2003; Muir *et al*., 2004; Harder *et al*., 2006). Similar studies are lacking in the UK. It might, therefore, be useful if the economic advantage of persistency and its association with longevity, health (including traits associated with lameness) and fertility traits were evaluated under UK conditions to establish whether or not persistency can be included in a broader selection index for improved productive life.

7.6.3 Housing Systems

The results of the association between different housing systems and flooring conditions and lameness traits suggest the need for continued work in the area of dairy cattle housing especially with regard to what type of flooring conditions will minimize the incidence of digital dermatitis. With respect to the locomotion type traits analysed in this study, there may be need to modify the genetic evaluation procedures for lameness traits in the UK on the basis of cubicle housing. Since Holstein UK records information on housing as part of its routine type classification scheme, including information on the number of months each cow has spent in cubicles at the time of classification in the national evaluation model may result in more accurate breeding values for bulls with regard to these lameness-related type traits since they demonstrated GxE.

7.6.4 Publication of Additional Traits

From the genetic analysis of locomotion and other type traits (chapter 4), it was clear both genetically and phenotypically that cows with higher locomotion score, steeper foot angle, straighter hocks, flat and refine bones, better leg and feet composite and well-attached mammary udders will have improved walking ability. Bone quality is an entirely new trait in the UK type classification scheme. Breeding values for the trait should be published by breeding companies. This would help in the identification and retention of the best candidate genotypes for breeding in order to minimize lameness cases in the UK dairy cow population. Not only is bone quality substantially correlated with other locomotion type traits (chapter 4), longevity and DD (chapter 5), it has also been found to have a strong genetic correlation with dairy character (Angularity in the UK) and milk production (Gordon and Shannon, 2002).

Similarly, breeding companies should also publish breeding values for DD in order to enable farmers to select the sires whose daughters have the highest resistance to the problem. Though the heritability estimate for DD is low, there is still genetic variation for the trait among cows, and DD is a widely acknowledged problem in most UK dairy farms.

Furthermore, given veterinary costs and the relationship between DD and production, reproductive performance, involuntary culling rate and overall welfare of the cow (Argaez-Rodriguez *et al.*, 1997; Hernandez *et al.*, 2001; Garbarino *et al.*, 2004; chapter 5) an economic value (EV) for DD should be calculated. The EV of lameness in the current UK £PLI as estimated by Stott *et al.* (2005) is £0.99 per percent incidence. Taking into account the cost of DD incidence may increase this estimate. It might also be worthwhile considering incorporating DD into the breeding goal to help to reduce health costs and improve cow welfare standards. Protein yield is a component production trait in the current UK £PLI making it necessary to determine the correlation between DD and protein. It was not possible to do this in my study as protein EBVs were not available.

In addition to production traits and lameness, the current UK £PLI also includes mastitis which is an important health trait. Farmers and dairy breeders are recognizing the value of improving lameness, somatic cell count (SCC), fertility and longevity in order to increase the efficiency of their operations. Future study might consider it desirable to evaluate the associations between lameness-related type traits, particularly bone quality, and other hoof and skin-related causes of lameness as well as other health problems such as SCC. Such a study might warrant broadening of existing selection indices in order to improve the overall breeding goal of the industry, which is profit through an improved quality of product and decreased treatment costs for lameness and mastitis.

7.7 Conclusions

Results from this thesis show that cubicle housing has a detrimental effect on locomotion type traits, and that allowing cows access to pasture reduces the incidence of lameness and the occurrence of diseases which cause lameness such as digital dermatitis. Nonetheless, the importance of good management is emphasized. It has been demonstrated in this thesis that bone quality is a useful type trait to collect in the UK and that bone quality and digital dermatitis should be included in future selection indices for optimal productive life and improved dairy cow welfare standards. However, as a result of the low heritability estimates for DD, performing selection index calculations is essential to determine the relative economic contribution of DD to the overall breeding goal of the dairy industry.

Using the genetic and phenotypic parameters derived in this study, it is now possible for breeding companies to predict and publish breeding values for bone quality and digital dermatitis for UK dairy bulls and cows.

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